ERDC/CHL TR-02-9

Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Investigations for Providing Wave Protection in Concert with Preserving the Maalaea Pipeline at Maalaea Harbor, Maui, Hawaii

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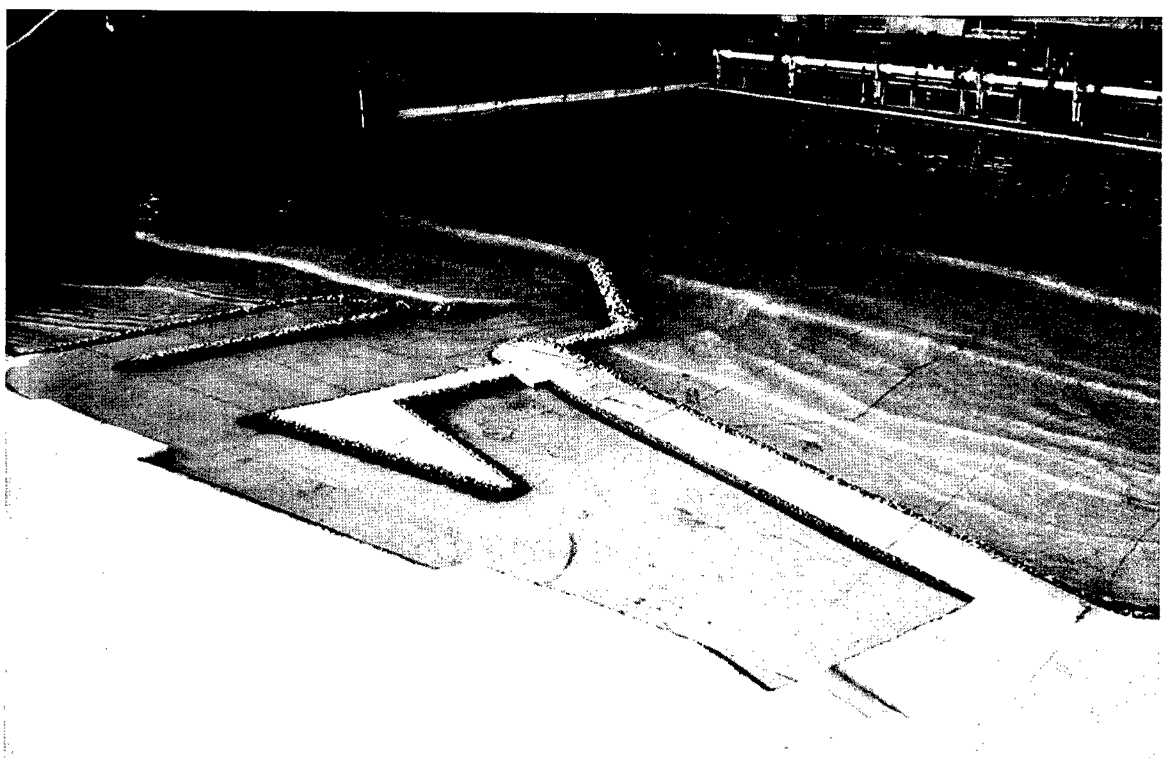
Robert D. Carver, Hugh F. Acuff, Stanley Boc, Edward F. Thompson, and Glenn B. Myrick

July 2002



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Investigations for Providing Wave Protection in Concert with Preserving the Maalaea Pipeline at Maalaea Harbor, Maui, Hawaii

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Final report

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Contents

Preface

A request for a model investigation of Maalaea Harbor, Maui, Hawaii, was initiated by the U.S. Army Engineer District, Honolulu, by e-mail in November 1999. Authorization for the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL) to perform the study subsequently was granted and funds were authorized by the Honolulu District in February 2000. Model design was immediately initiated and construction of the model was completed in May 2000.

Model testing was conducted at CHL during the period June 2000 through April 2001 by personnel of the Harbors and Entrances Branch (HNH) of CHL under the direction of Mr. Thomas R. Richardson, Director, CHL, and Mr. Dennis G. Markle, Chief, HNH. Tests were conducted by Messrs. Hugh Acuff and Glenn Myrick, civil engineering technicians, under the supervision of Mr. Robert Carver, Project Manager, all of CHL. Dr. Edward F. Thompson, research hydraulic engineer, CHL, prepared Appendix A, comparing results of the physical and numerical models.

Prior to the model investigation, Messrs. Acuff and Carver met with representatives of the Honolulu District and Mr. Acuff visited Maalaea Harbor to inspect the prototype site. During the course of the investigation, liaison was maintained by means of sponsor site visits, telephone conversations, e-mail, and monthly progress reports.

Mr. Stanley Boc of the Honolulu District provided technical oversight of the physical model, reviewed model results, and made recommendations and changes to the investigative approach. Messrs. Elden Chang (surfer), Ben Bland (surfer), Robert Luuwai (boater), and Nicholas Giaconi (Maalaea Harbor agent) visited ERDC during the course of the model study, providing validation of existing conditions and valuable input to experiments with the various alternatives. Messrs. Tim Johns, Director of Hawaii State Department of Land and Natural Resources, and Ray Jyo, the Honolulu District, also visited the model and provided management oversight and project support.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
miles (u.s. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

Prototype

Maalaea Harbor on the island of Maui (Figure 1) was first developed by the territory of Hawaii in 1952 and was modified by the territory and state in 1955, 1959, and 1979 to its present configuration (Figure 2). A Federal plan of

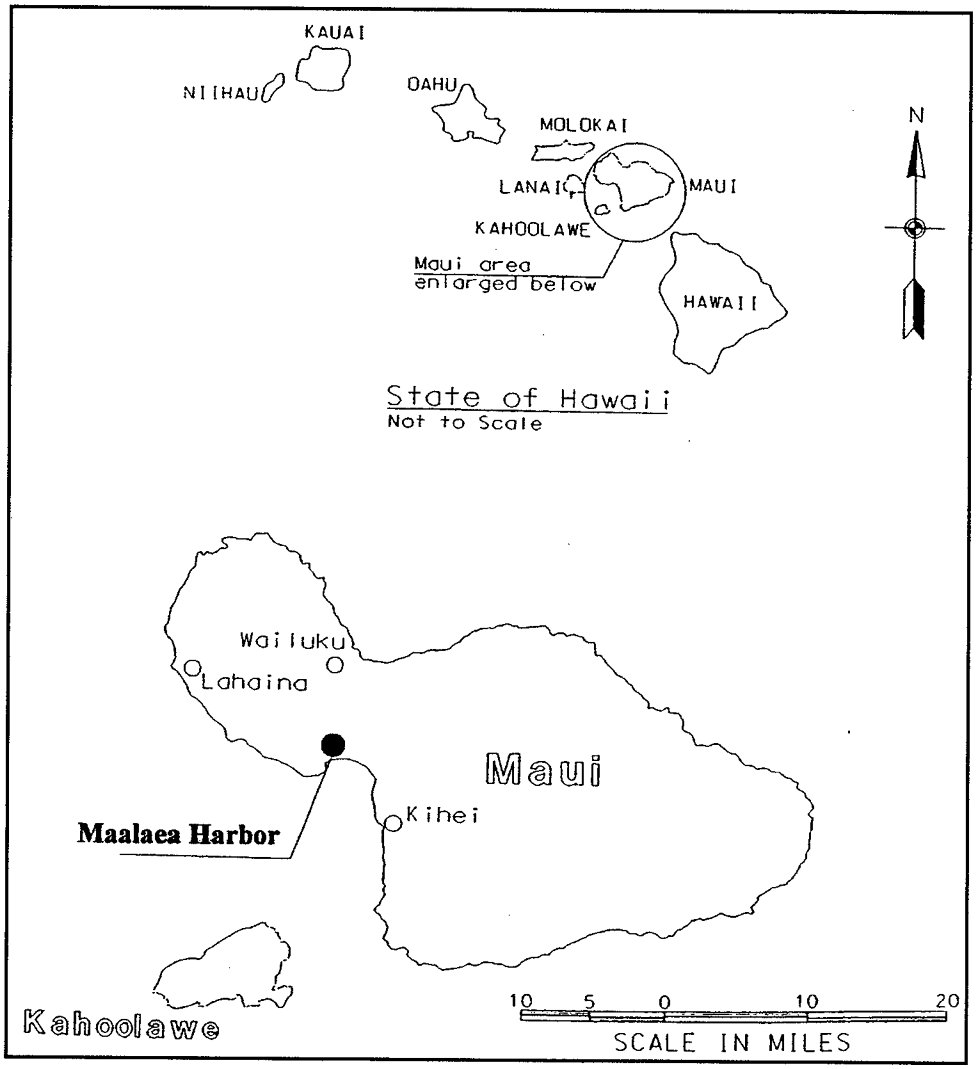

Figure 1. Location map of Maalaea light-draft harbor, island of Maui, HI

improvement was approved by Congress in 1968, but controversy surrounding the impact on the surf break known as Maalaea Pipeline (Figure 3) resulted in a postauthorization study and redesign in 1980. A General Design Memorandum and Final Environmental Impact Statement (FEIS) was approved by the U.S. Army Chief of Engineers in 1980.

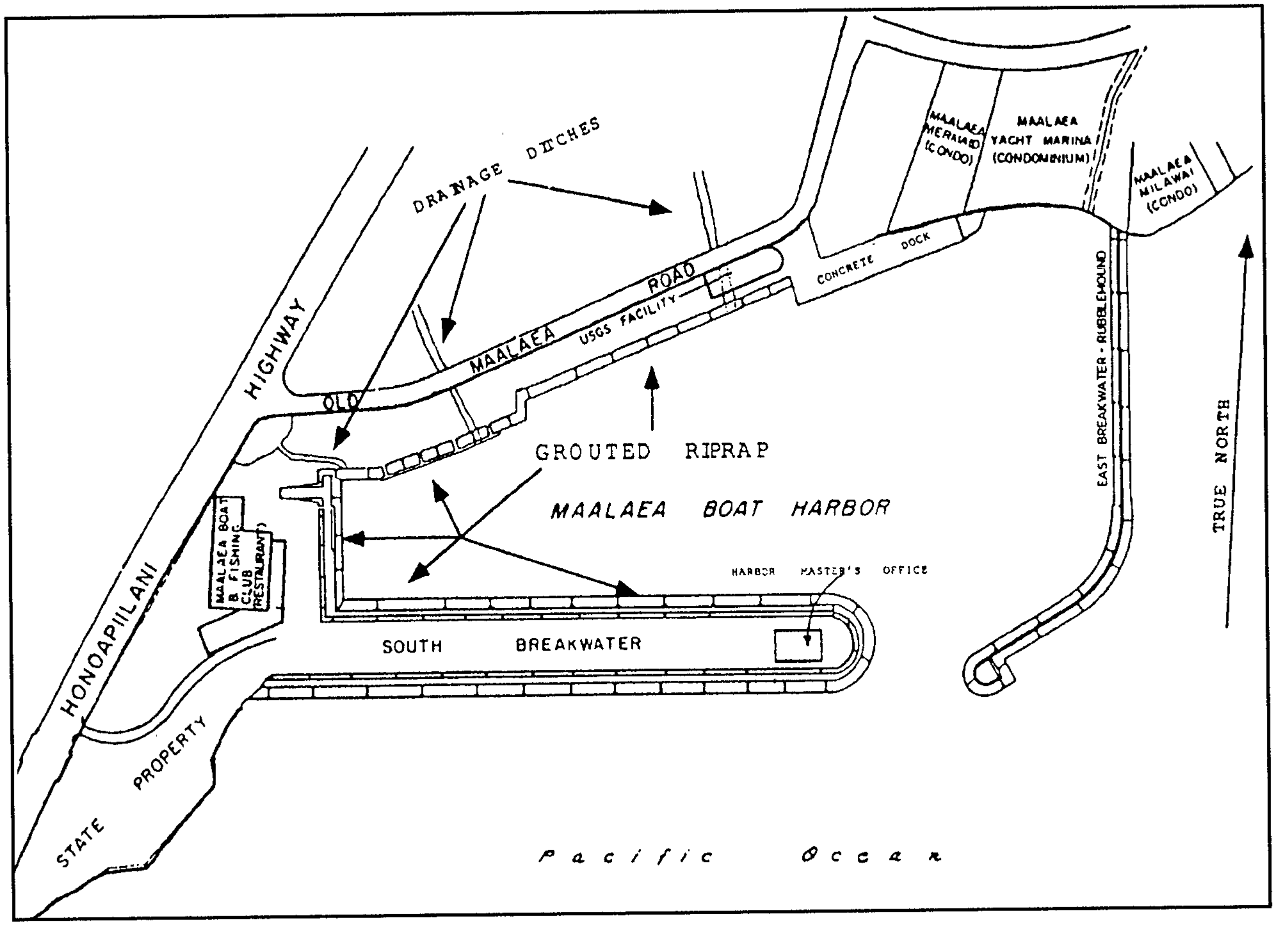

Figure 2. Maalaea light-draft harbor present configuration

The present harbor suffers from navigational hazards at the harbor entrance and a lack of safe berthing in some portions of the harbor. These conditions prevent full utilization of the available dredged water area within the harbor. At times, boat owners either leave the harbor with their vessels or secure their vessels and remain on board to prevent damages. Larger vessels leave the harbor during severe conditions as it is safer for these vessels to be out at sea.

After several years with no new civil works construction starts, Congress added construction funds for the Maalaea Harbor project to the 1990 water and energy appropriations bill. However, local concerns persisted, especially relative to the Maalaea Pipeline, and implementation of the project still awaits. A major purpose of this investigation is to evaluate alternate improvement plans relative to their possible effects on the Maalaea Pipeline.

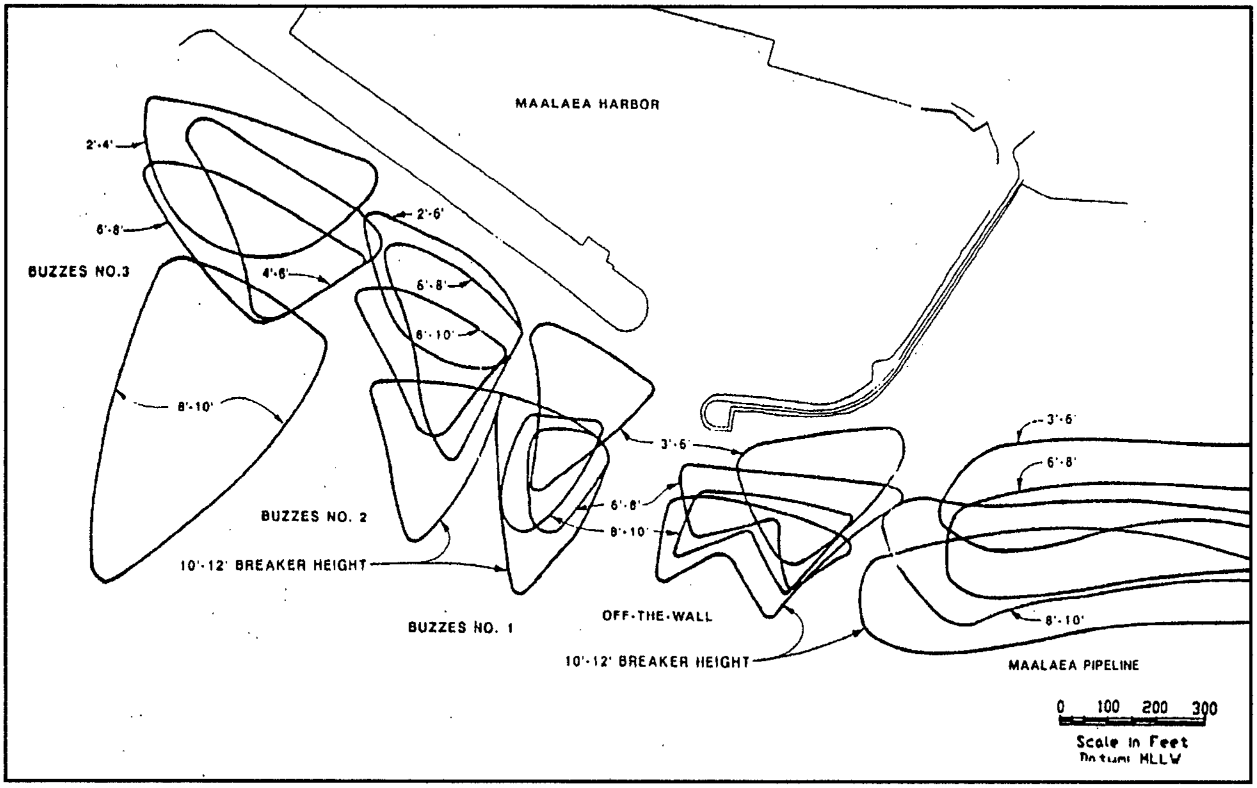

Figure 3. Surf break locations

Rationale for Proposed Improvements

The Federal purpose for the proposed action is specifically directed to the need for navigation improvements at Maalaea Harbor. Objectives include: (a) reduce wave heights within the harbor basin and entrance channel and the resultant damage to vessels, (b) reduce navigation hazards in the entrance channel, and (c) provide opportunity for the addition of berthing spaces and attendant harbor facilities

Hawaii Department of Land and Natural Resources (DLNR), who is the projects sponsor, will develop the internal improvements to the boat harbor that will be made feasible once the federal navigation improvements are completed. Objectives include improving the existing harbor support facilities and increasing the number of berths in the harbor.

At present, the harbor experiences unacceptably large internal wave heights and entrance channel navigation difficulties. Excessive wave energy within the harbor results from the existing configuration and alignment of the harbor entrance, which allows direct wave attack through the harbor entrance. The harbor is vulnerable to southern swells which occur over 50 percent of the year. Navigation is hazardous in the entrance channel for wave heights of 1.2 m (4 ft)[1]

[1] Units of measurement in this report are shown in SI units, followed by non-SI units in parenthesis. In addition, a table of factors for converting non-SI units of measurement used in figures, plates, and tables in this report is presented on page v.

and above. Surfers occasionally attempt to ride breaking waves through the harbor entrance, creating a hazard to themselves and other harbor users.

Purpose of Model Study

At the request of the U.S. Army Engineer District, Honolulu, a coastal model investigation was initiated by the U.S. Army Engineer Research and Developments Center's (ERDC) Coastal and Hydraulics Laboratory (CHL). Purposes of this investigation included (a) evaluating various structural alternatives for reducing wave heights within the harbor, (b) improving navigation conditions at the harbor entrance, and (c) evaluating the effects of the various alternatives on the surfing sites, which was believed to be a first for this type of investigation.

2 Model

Design of Model

The Maalaea Harbor model was constructed to an undistorted linear scale of 1:50, model to prototype. Scale selection was based on the following considerations:

a. Absolute size of model waves needed to replicate the Maalaea Pipeline.

b. Depth of water required to preclude excessive bottom friction.

c. Available shelter dimensions and area required for model construction.

d. Efficiency of model operation.

e. Available wave-generating and wave-measuring equipment.

A geometrically undistorted model was necessary to ensure accurate reproduction of wave patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law (Stevens et al. 1942). The scale relations used for design and operation of the model were as follows:

Characteristic	Dimension[1]	Scale Relations Model:Prototype
Length	L	L_r = 1:50
Area	L^2	$A_r = L^2$ = 1:2,500
Volume	L^3	$Vol_r = L^3$ = 1:125,000
Time	T	$T_r = L^{1/2}$ = 1:7.07
Velocity	L/T	$Vel_r = L^{1/2}$ = 1:7.07

[1]Dimensions are in terms of length and time.

Portions of the existing and proposed structures at Maalaea Harbor are rubble-mound structures. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type structure; thus the transmission and absorption of wave energy became a matter of concern in design of the 1:50-scale model. In small-scale hydraulic models, rubble-mound structures reflect more and absorb or dissipate less wave energy than geometrically similar prototype structures (LeMéhauté 1965). Also, the transmission of wave energy through a rubble-mound structure is less for the small-scale model than for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure replication of wave reflection and wave transmission. From previous findings for structures and wave conditions similar to those at Maalaea Harbor, it was determined that a close approximation of the correct wave-energy transmission characteristics would be obtained by increasing the size of the stone used in the model to approximately 1-1/3 times that required for geometric similarity. Accordingly, in constructing the rubble-mound structures in the model, stone sizes were computed linearly by scale and then multiplied by 1.33 to determine the actual sizes to be used in the model.

Model and Appurtenances

Vertical control for model construction was based on mean lower low water (mllw). Horizontal control was referenced to a local prototype grid system. The model (Figure 4) reproduced Maalaea Harbor and approximately 762 m (2,500 ft) of the Maui shoreline and underwater topography in the Pacific Ocean to an offshore depth of 13 m (42 ft) with a sloping transition to the wave generator pit elevation of -15 m (-50 ft) mllw.

Figure 4. General view of model

Model waves were generated by a 24-m (80-ft)-long vertical displacement, electro-hydraulic wave generator, capable of generating both regular and spectral waves. The vertical motion of the plunger produced a displacement of water incident to this motion. The generator was mounted on retractable casters which enabled it to be positioned to generate waves from the required directions.

An Automated Data Acquisition and Control System (ADACS), designed and constructed at ERDC (Figure 5), was used to generate and transmit wave generator control signals, monitor wave generator feedback, and analyze wave-height data at selected locations in the model. Basically, through the use of a minicomputer, ADACS recorded onto disc the electrical output of parallel-wire, capacitance-type wave gages that measured the change in water-surface elevation with respect to time. The output of ADACS was then analyzed to obtain the wave-height data.

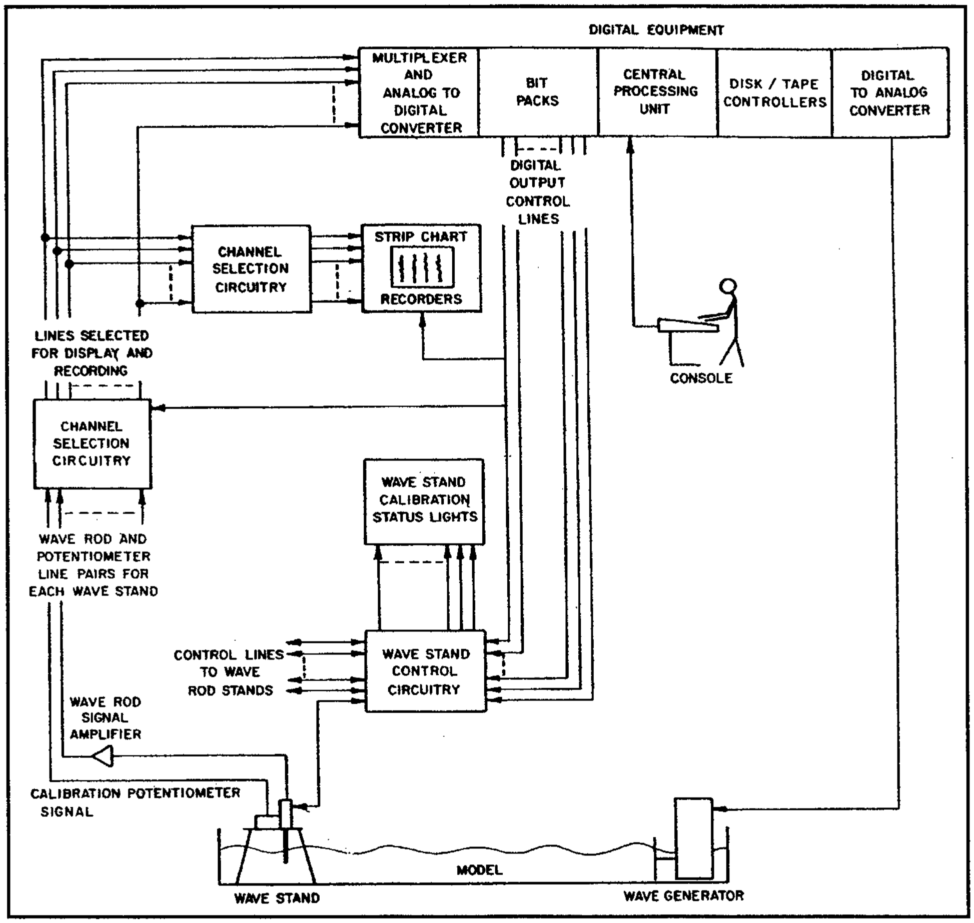

Figure 5. Automated data acquisition and control system

A 0.6-m (2-ft) solid layer of fiber wave absorber was placed around the inside perimeter of the model to dampen any wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

3 Experimental Conditions

Still-Water Level

Still-water levels (swl) for wave action models are selected so that the various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. These phenomena include the refraction of waves in the project area, the overtopping of structures by waves, the reflection of wave energy from various structures, and the transmission of wave energy through porous structures.

In most cases, it's desirable to select a model swl that closely approximates the higher stages which normally occur in the prototype for the following reasons:

a. The maximum amount of wave energy reaching a coastal area normally occurs during the higher water phase of the local tidal cycle.

b. Most storms moving onshore are characteristically accompanied by a higher water level due to wind tide and shoreward mass transport.

c. The selection of a high swl helps minimize model scale effects due to bottom friction.

d. When a high swl is selected, a model investigation yields more conservative results.

Swl's of +0.3 m (1.0 ft) and +0.7 m (2.3 ft) were selected for representation in this model investigation, representing mean sea level and mean higher high water, respectively.

Factors Influencing Selection of Experimental-Wave Characteristics

In planning the experimental program for a model investigation of harbor wave-action problems, it is necessary to select dimensions and directions for the experimental waves that will allow a realistic test of the proposed improvement plans and an accurate evaluation of the elements of the various proposals. Replicating the Maalaea Pipeline presents a particular challenge in that no exact data exist as to wave period, height, or direction.

Surface-wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interaction between individual wave components. The height and period of the maximum wave that can be generated by a given storm depend on wind speed, the length of time that wind of a given speed continues to blow, and the water distance (fetch) over which the wind blows. Selection of experimental-wave conditions entails evaluation of such factors as:

a. The fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can attack the problem area.

b. The frequency of occurrence and duration of storm winds from the different directions.

c. The alignment, size, and relative geographic position of the navigation entrance to the harbor.

d. Alignments, lengths, and locations of the various reflecting surfaces inside the harbor.

Selection of Experimental Wave Directions

Maalaea Harbor is exposed to waves from Kona storms, southern hemisphere swells, tropical storms, and hurricanes. It is exposed to direct attack by waves approaching from 160 deg through 185 deg and from 213 deg through 217 deg as shown in Figure 6. Other southerly waves which are reflected and refracted by the land masses of Maui east and west of Maalaea Bay, and the Island of Kahoolawe also occur, but much of their energy is dissipated in the reflection/ refraction process, so they are generally not as severe as those from 160-185 deg and 213-217 deg. A recent numerical investigation of Maalaea Harbor by Hadley, Thompson, and Wilson (1998), that considered deepwater wave directions from 135-270 deg, showed that approximately 90 percent of the unacceptable conditions in the harbor, i.e., wave heights in excess of 0.3 m (1 ft), were created by waves originating between 157.5 and 180 deg. Thus, it was decided to focus most of the physical model study effort on this critical window of exposure.

At the onset of the study, the exact direction of the incoming Maalaea Pipeline was unknown; however, based on information provided by the Honolulu District and local surfers, it was thought to be generally from the south and thus it should have an approaching azimuth of around 180 deg. Thus, one test direction was initially assumed to have a local direction of 180 deg, covering one side of the critical window of exposure. A majority of the proposed improvement plans have the entrance channel aligned toward the southeast; therefore, the other extreme for the critical window of exposure (160 deg) was chosen as the second direction. A third and final wave direction of 215 deg was chosen to represent effects of the 213-217-deg window shown in Figure 6. Model layout and corresponding wave machine positions for the chosen wave directions are shown in Figure 7.

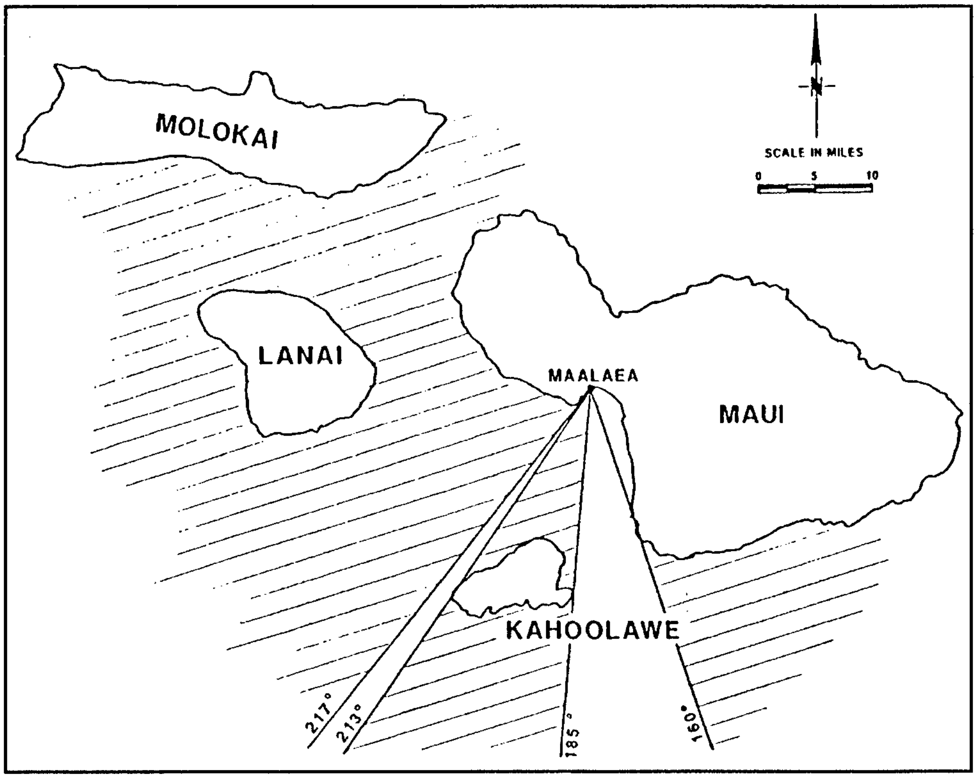

Figure 6. Wave exposure

Verification of Surf Sites: Maalaea Pipeline, Buzzes, and Off-the-Wall

The most critical wave conditions to verify were the surfing waves that compose the Maalaea Pipeline. There were a number of variables to consider. These included local wave direction, wave period and height, and swl.

During the week of 19-23 June 2000, Stanley Boc of the Honolulu District, Nicholas Giaconi, Maalaea Harbor agent, and Eldon Chang, surfer, visited the model and worked in concert with CHL personnel to verify the Maalaea Pipeline in the 1:50 scale model. Initially, videotapes of the prototype surfing waves were reviewed and it was determined that the periods ranged from 14 to 18 sec, consistent with the deepwater wave data presented by Hadley, Thompson, and Wilson (1998). The videotapes also showed the general area where the waves broke, implicitly allowing the wave heights to be estimated.

The approach in the model was to adjust the major parameters until a set of wave conditions was obtained that best matched those in the prototype. As previously discussed, the wave direction was known to be in the 160- to 180-deg range. Model observations showed the best rolling action on breaking appeared to be achieved at 180 deg, tentatively establishing the wave direction. Next, wave heights in the 1.2-m (4-ft) to 2.4-m (8-ft) range were observed for wave periods of 14, 16, 17, and 18 sec. All agreed that 1.8-m (6-ft) to 2.4-m (8-ft) waves at periods of 16 to 18 sec closely resembled the surfing waves in the videotapes.

Based on the prototype experiences of Chang and Giaconi, it was decided that the 18-sec, 2.4-m (8-ft) waves best represented the Maalaea Pipeline. Swl's of +0.3 m (+1.0 ft) and +0.7 m (+2.3) ft mllw were observed. The waves looked similar at both swl's; however, results at the +0.3-m (+1.0-ft) swl appeared to be in slightly more compatible with prototype conditions than those observed at the +0.7-m (+2.3-ft) swl.

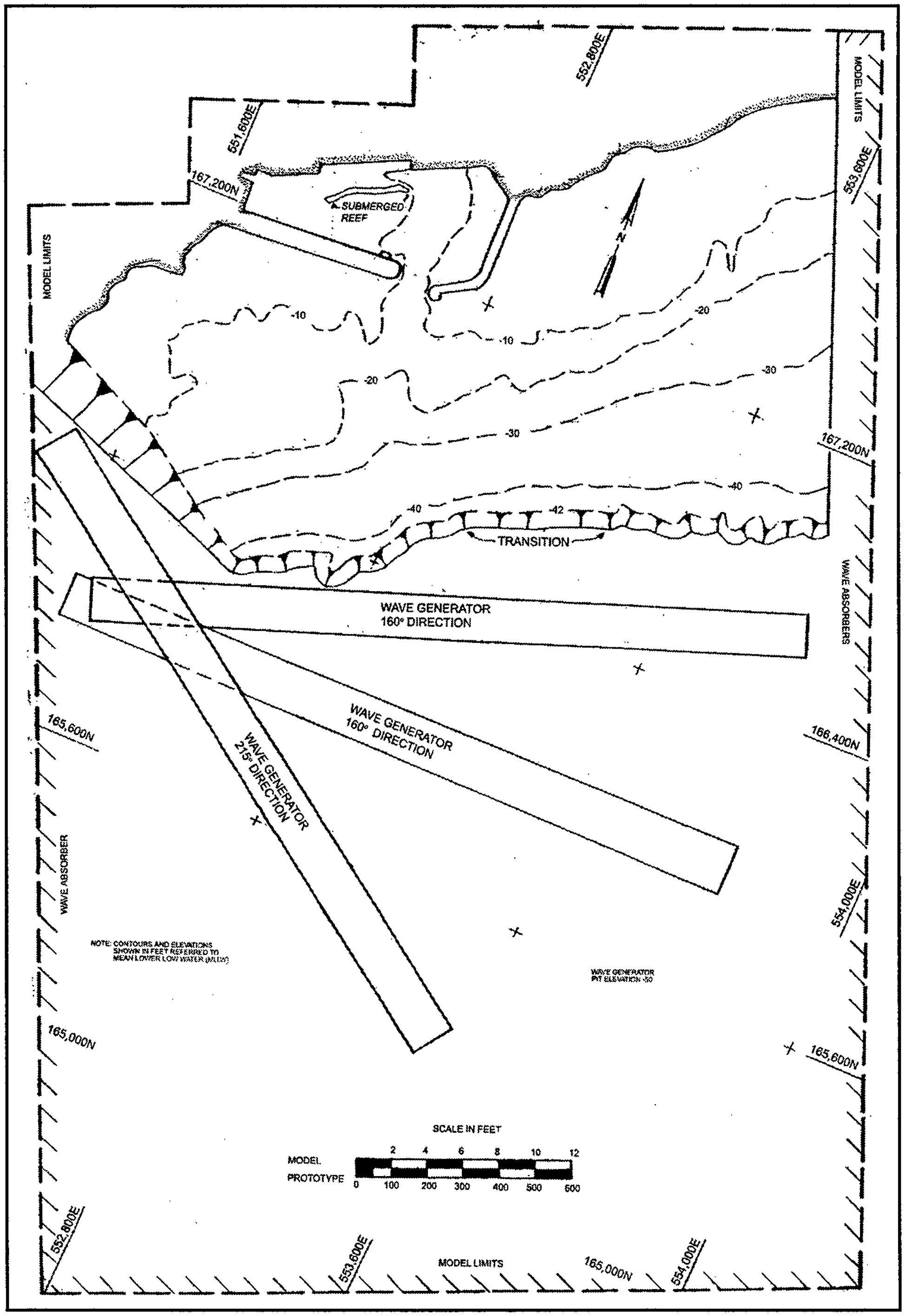

Figure 7. Model layout and wave machine positions

Thus, the Maalaea Pipeline is estimated to be an 18-sec, 2.4-m (8-ft) wave with a local wave direction of 180 deg; however, excellent surfing conditions occur for a range of wave conditions. Therefore, it was decided to conduct studies with 1.2-m (4-ft) to 2.4-m (8-ft) waves at periods of 14, 16, and 18 sec. The various plans could then be evaluated relative to their effects on this range of surfing conditions, improved wave conditions in the harbor, and navigation improvements.

During the week of 14-18 August 2000, Ben Bland, a local surfer and boater familiar with Maalaea Harbor, visited the model. Bland confirmed that the 18-sec, 2.4-m (8-ft) waves, impinging from the 180-deg wave direction, appeared to accurately reproduce the Maalaea Pipeline. Consistent with the observations of Chang, Bland also concluded that the Buzzes and Off-the-Wall surf sites were accurately represented in the physical model.

Selection of Experimental Waves for Harbor Response

In addition to the 14-, 16-, and 18-sec waves previously described, 8- and 11-sec waves were added to help evaluate harbor response. The 14-, 16-, and 18-sec surfing waves were monochromatic in form, i.e., all waves in the wave train were approximately the same height. However, the 8- and 11-sec waves, more typical of local storms, were assumed to be irregular. For the 8- and 11-sec wave periods, unidirectional Joint North Sea Wave Project (JONSWAP) wave spectra were generated. Plots of typical spectra are shown in Figure 8. As summarized in the following tabulation, a total of 11 test waves were selected for use in the model:

Selected Test Waves

Period, sec	Hs, ft
8	6
11	8
14	4, 6, 8
16	4, 6, 8
18	4, 6, 8

All wave heights reported herein represent the average height of the highest one-third of the waves or Hs.

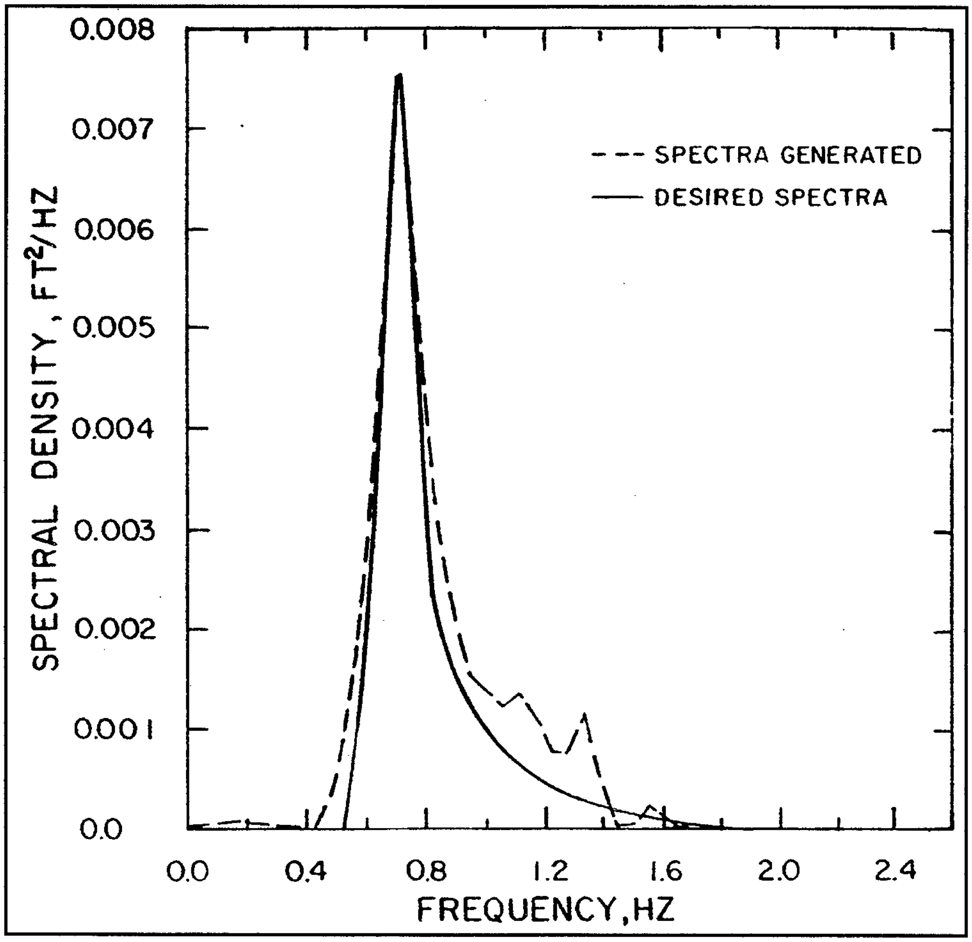

Figure 8. Typical energy density versus frequency plots (model terms) for 11-sec, 8-ft test waves

4 Experiments and Results

Harbor and Surf Site Wave Heights for Existing Conditions

Prior to investigating the various improvement plans, comprehensive studies were conducted for existing conditions (Plate 1). Wave-height data were obtained in the surf zone (Gages 1-6), at the harbor entrance (Gages 7 and 8), and in the interior of the harbor (Gages 9-15). Results for existing conditions are presented in Table 1. These data show maximum wave heights in the surf zone of 4.3 m (14 ft) to 5.2 m (17 ft) for 18-sec, 2.4 m- (8-ft) incident waves. Also, most wave heights within the harbor exceed 0.3 m (1 ft) and a significant number are above 0.6 m (2 ft) with several above 1.2 m (4 ft). It is interesting to note that experience at Maalaea Harbor has shown the area in the vicinity of Gage 11 to be one the most troublesome in terms of damage. Consistent with these observations, the largest waves measured within the model harbor were at Gage 11. It should also be noted that increasing the swl from +0.3 m (+1.0 ft) to +0.7 m (+2.3 ft) can produce a significant increase in wave heights within the harbor for some of the larger incident conditions. This results primarily from overtopping of the south breakwater. Typical wave patterns for existing conditions are shown in Photos 1-12.

Navigation Experiments for Existing Conditions

Robert K. Luuwai, local boater familiar with Maalaea Harbor, visited the model and participated in the navigation studies of existing conditions. Experience at Maalaea Harbor has shown that the longer period waves, approaching from the south, tend to be the most troublesome. Thus, navigation tests were conducted with 0.6-m (2-ft), 1.2-m (4-ft), 1.8-m (6-ft), and 2.4-m (8-ft), 18-sec waves, approaching from 180 deg. All tests were conducted at an swl of +0.3-m (+1.0 ft) mllw. A 0.3-m- (1-ft-) long, displacement-hull, model vessel (Figure 9) was used in the experiments. This simulated a 15-m (50-ft) vessel in the prototype which is typical of the larger boats using the harbor.

Experience at Maalaea Harbor has also shown that vessels of this size typically begin to have difficulty entering/exiting the harbor at wave heights of around 1.2 m (4 ft) and encounter severe problems for 1.8 m (6 ft) and larger waves. To simulate the inherent randomness in test results of this type, approximately 10 enter/exit maneuvers were attempted for each wave height. The 0.6-m (2-ft) waves posed no problems. The majority of attempts to enter/exit the harbor were successful at a 1.2-m (4-ft) wave height; however, operators found it more difficult to maintain control. For 1.8-m (6-ft) waves, operators experienced major control problems and ran aground about two-thirds of the time.

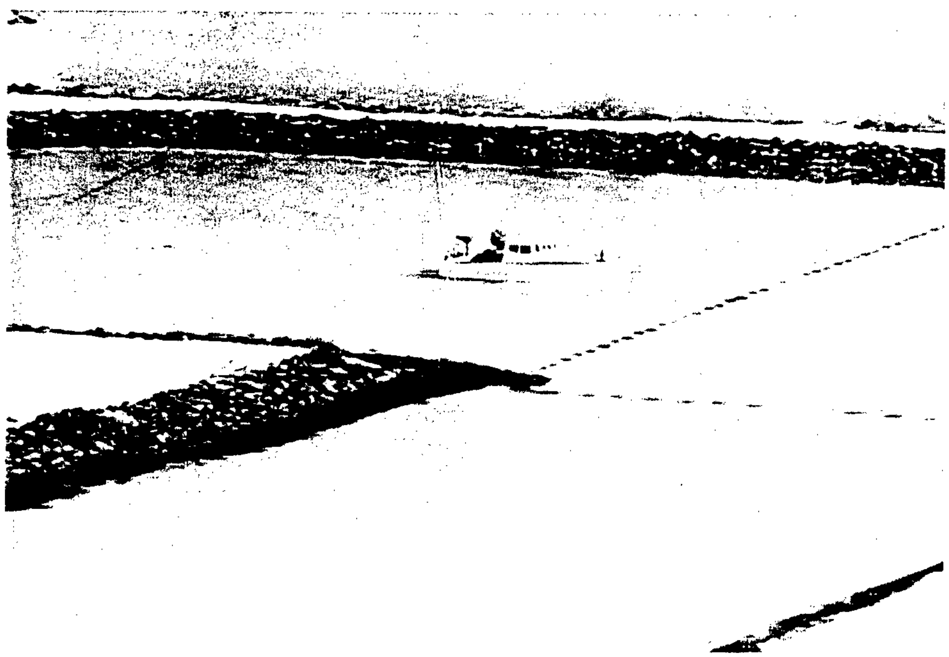

Figure 9. Model boat

When the wave heights were increased to 2.4 m (8 ft), operators found it impossible to enter/exit the harbor safely. As summarized in the following tabulation and verified by Luuwai's experience, it was concluded that 1.2 m (4 ft) was the upper limit of safe passage.

Wave Height, ft	Safe Entries/Exits, Percent
2	100
4	80
6	30
8	0

Investigations of Improvement Alternatives

A total of nine improvement plans were investigated. These included five major alternatives and four others that represented variations of the major alternatives. Two of these were restricted to modifications within the harbor; whereas, the others included a new entrance channel, breakwater, and related external additions. Descriptions and results of experiments for the various alternatives are summarized in the following paragraphs. Originally, a total of eight alternatives were considered for possible use at Maalaea Harbor. However, prior to the present investigation, three of these were eliminated from consideration through numerical or analytical evaluation. Thus, this report addresses Alternatives 1, 2, 3, 6, and 8 (as defined in Supplement II of the

Environmental Impact Statement (EIS) for Maalaea Harbor), and related subalternatives that were developed during the course of the study.

As will be expanded upon in the following paragraphs, investigations conducted of Alternatives 1 through 1d showed that maintaining the east breakwater at its present length produced a significant decrease in wave heights within the harbor, relative to the shortened east breakwater proposed in Alternative 1. Thus, this improvement was carried forward in the studies of Alternatives 2 and 3, directly creating Alternatives 2a and 3a.

Effects on harbor and surf site waves

Experiments to evaluate improvements within the harbor and possible effects on the surf sites were generally conducted simultaneously and have a close cause and effect relationship. Thus, they are reported concurrently.

Alternative 1 (Plate 2) included a 142-m- (466-ft-) long extension to the existing south breakwater; shortening the existing east breakwater by 24 m (80 ft), addition of a triangular shaped mole on the seaward side of the existing south breakwater; a 4.6-m- (15-ft-) deep, 46-m- (150-ft-) wide by 183-m- (600-ft-) long entrance channel; and a 3.7-m- (12-ft-) deep turning basin. The proposed south breakwater extension will be constructed to a crest elevation of +4 m (+13 ft) mllw and armored with 5.5-tonne (6-ton) concrete armor units placed on a 1V:2H slope. In addition, this plan included a 220-m- (720-ft-) long interior reveted mole at an el of +2.1 m (+7 ft) and a 2.4-m- (8-ft-) deep berthing area adjacent to the existing east breakwater and a new irregularly shaped center mole at an el of +2.1 m (+7 ft) which was accessed from the north shore of the harbor.

Since some of the alternatives give very similar results, a later section of this report will further reduce the detailed wave height data to help identify trends and compare alternatives. As expected and shown in Table 2, a significant reduction in wave heights within the harbor was observed with this plan proving most effective for the 215-deg wave direction. Visual observations confirmed by the surf zone gages (Gages 1-6) indicated no measurable effects on the Maalaea Pipeline. As expected, Off-the-Wall and Buzzes 1 were eliminated. Buzzes 2 and 3 appeared to be unaffected. Typical wave patterns with Alternative 1 installed are presented in Photos 13-24.

Even though Alternative 1 significantly improved wave conditions within the harbor, many wave heights were still above 0.6 m (2 ft) and Gage 11, in the southwest corner of the harbor, often registered above 0.9 m (3 ft). Therefore, with the help of the Honolulu District, two variations of Alternative 1 were conceived and studied at the 160-deg wave direction. The 160-deg wave direction was chosen for assessing the subplans because the harbor was most exposed for this incident direction.

Alternative 1a, shown in Plate 3, was the same as Alternative 1 except the existing east breakwater was extended 24 m (80 ft), making it the same as it presently exists in the prototype. Experimental results for Alternative 1a, presented in Table 3, show a further improvement in the harbor with more values dropping below 0.6 m (2 ft). Surf site results were the same as those observed for Alternative 1. Photos 25-28 show selected wave patterns for Alternative 1a.

Alternative 1b was the same as 1a, except a 2.7- to 4.5-tonne (3- to 5-ton) stone absorber was added at the channel-side base of the south breakwater as shown in Plate 4. Data presented in Table 4 show only a slight reduction in wave heights within the harbor relative to Alternative 1a. Surf site results were the same as those observed for Alternatives 1 and 1a.

Alternative 1c (Plate 5) was the same as Alternative 1a, except the 142-m- (466-ft-) long extension to the existing south breakwater was increased by 20 m (64 ft), yielding a total length of 162 m (530 ft). Alternative 1c was studied at the 160-deg wave direction, and, as shown in Table 5, some further reduction of wave heights within the harbor was noted. Surf site results were the same as those observed for Alternatives 1, 1a, and 1b. Selected wave patterns are shown in Photos 29-32.

Alternative 1d (Plate 6) was the same as Alternative 1c, except the south breakwater was lengthened to total of 183 m (600 ft). As expected, and shown in Table 6, some further reduction of the harbor wave heights was observed. Surf site results were the same as those observed for Alternatives 1, 1a, 1b, and 1c. At some length, further extension of the south breakwater would impact the Maalaea Pipeline; however, based on visual observations and data presented in Table 6, no significant changes were evident with the 183-m (600-ft) extension. Photos 33-36 show typical wave patterns for Alternative 1d.

Alternative 2a (Plate 7) was developed in an effort to minimize potential impacts to Buzzes 1 surf site and minimize the amount of fill material needed for the breakwater extension. This plan was the same as Alternative 1a, except the revetted mole on the south breakwater was removed and the breakwater extension was directly connected to the existing south breakwater. Results of wave studies, conducted at the 180- and 215-deg wave directions, are presented in Table 7. As expected, observed wave heights are generally similar to Alternative 1a. Also, model observations showed that removing the revetted mole did not have a significant effect on Buzzes 1 surf site. Some minor changes in reflection characteristics were observed; however, as shown in Photos 37-42, overall wave patterns were not appreciably affected.

Alternative 3a (Plate 8) was similar to Alternative 2a, except that it used a detached breakwater instead of an extension to the existing south breakwater. The detached breakwater was 198 m (650 ft) long with the first 104 m (340 ft) of the structure constructed parallel to the existing south breakwater with outer head terminating in the same location as the breakwater extension used in Alternatives 1a and 2a. Wave height measurements, presented in Table 8 show that, relative to the previously described alternatives, Alternative 3 yielded similar to slightly higher wave heights within the harbor. The Maalaea Pipeline and Buzzes 3 were unaffected. Off-the-Wall and Buzzes 1 were eliminated. Buzzes 2 was impacted; however, some rideable waves appeared to still exist. Typical wave patterns are shown in Photos 43-54.

Alternative 6 (Plate 9) employed an internal breakwater which was 29 m (95 ft) wide, 152 m (500 ft) long, and extended from the east end of the existing south breakwater toward the northeast corner of the harbor. Since an improvement to Alternative 6 (Alternative 8) was being designed during the period Alternative 6 was investigated, only limited experiments were conducted with Alternative 6. Based on visual observations of wave conditions, Alternative 6 appeared to produce little improvement in wave conditions within the harbor. Also, based on visual observations and as would be expected, none of the surf sites were impacted by this alternative.

Alternative 8 (Plate 10) included a new mole constructed to an el of +2.1 m (+7.0 ft) attached to the existing south breakwater, a new breakwater el +2.4 m (+8 ft) approximately parallel to the existing east breakwater, and a 4.6-m- (15-ft-) deep entrance channel. Wave height measurements, presented in Table 9, show relative to Alternatives 1a-3a, Alternative 8 generally yielded higher wave heights within the harbor. As with Alternative 6, none of the surf sites were affected. Photos 55-66 show typical wave patterns.

Effects on navigation

Navigation was investigated for selected alternatives. Due to the geometric similarity of Alternatives 1, 1a, 1b, and 2a, studies were conducted only with Alternative 1a. During the period Alternatives 1c and 1d were being investigated for effects on harbor and surf site waves, the model vessel was undergoing extensive repairs and was thus unavailable. As described in the following paragraphs, navigation studies were conducted with Alternatives 1a, 3a, 6, and 8.

Navigation results for Alternative 1a showed a significant improvement over existing conditions. No control problems were encountered for the 0.6-m (2-ft) and 1.2-m (4-ft) waves. At the 1.8-m (6-ft) wave height, the majority of attempts to enter/exit the harbor were successful. Results for the 2.4-m (8-ft) waves were mixed with about half the attempts to enter the harbor being successful. In summary, results were as follows:

Wave Height, ft	Safe Entries/Exits, Percent
2	100
4	100
6	90
8	50

Navigation results for Alternative 3a showed significant improvement over existing conditions. No control problems were encountered for the 0.6-m (2-ft) and 1.2-m (4-ft) waves. At the 1.8-m (6-ft) wave height, over half the attempts to enter/exit the harbor were successful. As compared to Alternative 1a, a strong current flowing parallel to the existing south breakwater made navigating the 1.8-m (6-ft) waves more difficult and entering/exiting for 2.4 m (8-ft) waves was not possible. In summary, results were as follows:

Wave Height, ft	Safe Entries/Exits, Percent
2	100
4	100
6	60
8	0

Navigation results for Alternative 6 showed increased difficulty relative to existing conditions. Generally, the restriction created at the harbor mouth by the new breakwater tended to make navigation through the entrance more difficult. No control problems were encountered for the 0.6-m (2-ft) waves. At the 1.2-m (4-ft) wave height, about half the attempts to enter/exit the harbor were successful. Navigating the 1.8-m (6-ft) waves was difficult, with only 20 percent of the attempts being successful. No successful attempts were completed for 2.4-m (8-ft) waves. In summary, results were as follows:

Wave Height, ft	Safe Entries/Exits, Percent
2	100
4	50
6	20
8	0

Navigation results for Alternative 8 were slightly improved relative to Alternative 6 and similar to those obtained for existing conditions. Again, no control problems were encountered for the 0.6-m (2-ft) waves. At the 1.2-m (4-ft) wave height, about two-thirds of the attempts to enter/exit the harbor were successful. Only about one-third of the enter/exit attempts were successful when the wave height was raised to 1.8 m (6 ft). Navigating the 2.4-m (8-ft) waves was impossible. In summary, results were as follows:

Wave Height, ft	Safe Entries/Exits, Percent
2	100
4	70
6	30
8	0

During the wave height and navigation experiments conducted with Alternative 8, it was noticed that current velocities in the constricted area between the new mole and the existing north embankment appeared to be higher than those estimated for previous plans. Thus, it was decided to measure middepth currents at the harbor entrance and three other locations, as shown in Plate 10. Results of these tests, conducted at the 180-deg wave direction, are presented in Tables 10 and 11. Peak values up to 2.2 m/sec (7.3 ft/sec) in the harbor entrance are consistent with the severe control problems experienced by boats in this area. Peak values up to 1.2 m/sec (3.9 ft/sec) at Gages 2, 3, and 4 are below the threshold at which major control problems develop; however, they are undesirable in such a confined area where precise control is needed.

Summary and Discussion of Results

As previously discussed, a massive amount of wave height data is presented in Tables 1-9. Therefore, in an effort to facilitate comparison of the major alternatives (1, 1a, 2a, 3a, and 8), results for the surf zone, Gages 1-6, and the harbor, Gages 9-14, are averaged and presented in Tables 12 and 13. These data show surf zone wave heights are consistently similar for all alternatives investigated. This supports model observations that none of the alternatives appeared to have a negative impact on the Maalaea Pipeline. Alternatives 1, 1a, 1b, 1c, 1d, and 2a eliminated Off-the-Wall and Buzzes 1. Alternative 3a eliminated Off-the-Wall and Buzzes 1 and produced a noticeable visual difference at Buzzes 2. As expected, Alternatives 6 and 8 had no impact on any of the surf sites, based on visual observations.

The data presented in Tables 12 and 13 verify general model observations and show that Alternatives 1a, 2a, and 3a give the best and very similar performance, followed by Alternative 1, with Alternative 8 showing the least improvement relative to existing conditions. Intuitively, these results seem very reasonable in that Alternatives 1a and 2a are the most similar and afford the most protection to the harbor while Alternative 8 provides no entrance channel protection.

Navigation study results for Alternative 1a showed a significant improvement over existing conditions. Navigation test results for Alternative 3a showed some improvement over existing conditions; however, the improvement was significantly less than that observed for Alternative 1a due to a strong current flowing parallel to the existing south breakwater. Alternatives 6 and 8 produced no improvement relative to existing conditions.

Prior to the physical model study described in this report, various Maalaea Harbor layout alternatives were investigated with numerical model studies. Although the alternatives studied in the physical model were not intended to exactly match those in any particular numerical model study, there are enough similarities in the studies to merit a brief comparison. As described in Appendix A, comparisons were made between existing conditions, Alternative 1, and Alternative 8. As would be expected, some variation in results between the physical and numerical models is evident; however, the general predicted performance of a given alternative is similar in both modeling approaches. Please see Appendix A for details.

5 Conclusions

Based on results of the coastal model investigation described herein, comparisons with prototype wave data and videos of prototype waves, and opinions of visitors familiar with local surfing conditions at Maalaea Harbor, it is concluded that:

a. The model replicated both the waves that comprise the Maalaea Pipeline and the unacceptably high wave conditions that presently exist within the harbor.

b. The stone absorber, used in Alternative 1b, and the increased lengths of the south breakwater extension studied for Alternatives 1c and 1d produced only a small increase in harbor performance; therefore, Alternative 1a appears to be the best choice of all the variations of Alternative 1 investigated.

c. Results of experiments for Alternative 2a showed that removing the revetted mole from the south breakwater did not significantly improve waves at the Buzzes surf sites, based on visual observations.

d. Navigation study results for Alternative 1a showed a significant improvement over existing conditions with the level of safe harbor entry/exit being raised to the 1.8 m (6 ft).

e. Wave height reduction within the harbor was very similar for Alternatives 1a, 2a, and 3a.

f. Navigation test results for Alternative 3a showed improvement over existing conditions; however, as compared to Alternative 1a, a strong current flowing parallel to the existing south breakwater made navigating the 1.8-m (6-ft) waves more difficult and entering/exiting for 2.4-m (8-ft) waves was not possible.

g. Based on visual observations, Alternative 6 appeared to produce little improvement in wave conditions within the harbor and the restriction created at the harbor mouth by the new breakwater tended to make navigation through the entrance more difficult and worse than existing conditions.

h. Alternative 8 significantly reduced wave heights immediately behind the existing south breakwater (Gages 9 and 10); however, performance improvements at the other gage locations was significantly below that observed for Alternatives 1a, 2a, and 3a.

i. Peak current velocities up to 1.2 m/sec (3.9 ft/sec), observed for Alternative 8 at Gages 2, 3, and 4, are undesirable in such a confined area where relatively precise control is needed.

j. Based on the exhaustive wave data presented herein, observations by model operators with extensive experience, and observations of visitors familiar with the Maalaea Pipeline, it is concluded that none of the alternatives investigated herein should have a measurable effect on the Maalaea Pipeline. Alternatives 1, 1a, 1b, 1c, 1d, 2a, and 3a eliminated Off-the-Wall and Buzzes 1 surf sites. As expected, Alternatives 6 and 8 had no impact on any of the surf sites.

k. As shown in Appendix A, some variation in results between the physical and numerical models is evident; however, the general predicted performance of a given alternative is similar with both modeling approaches.

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Table 1
Wave Heights for Existing Conditions

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl ; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	6.4	6.9	7.5	7.2	7.4	8.1	6.0	5.6	2.2	2.0	2.6	1.8	2.1	2.7	2.0
11	8	8.3	8.9	8.1	9.8	9.6	9.1	7.2	6.5	2.2	2.2	3.0	1.9	2.2	3.0	2.3
14	4	4.7	4.8	5.1	6.4	5.3	7.0	5.7	6.4	2.9	1.3	2.3	1.4	4.4	3.2	1.8
14	6	8.5	9.0	10.3	9.6	9.2	10.2	9.4	9.0	3.3	1.3	4.2	2.0	3.7	3.8	2.8
14	8	11.3	11.0	11.7	12.9	13.1	14.3	11.6	7.8	2.2	1.2	4.0	1.9	3.0	2.9	2.2
16	4	6.4	7.9	9.9	4.7	5.6	6.2	4.3	4.7	2.1	2.3	3.4	1.4	1.9	2.1	1.5
16	6	11.7	13.3	13.7	8.1	9.7	9.1	6.8	7.6	3.4	2.5	3.7	2.1	3.0	3.0	1.9
16	8	13.5	15.1	10.7	11.3	12.6	10.2	7.7	6.7	3.5	2.3	3.1	1.9	3.3	2.9	2.0
18	4	7.6	8.5	10.6	6.2	7.4	9.5	8.5	7.0	1.3	1.7	2.1	0.8	1.4	2.3	1.5
18	6	13.1	13.4	10.2	10.3	9.6	10.7	9.6	7.5	1.1	2.0	3.8	1.0	1.6	3.1	1.9
18	8	17.0	16.4	8.9	16.8	13.6	7.7	7.4	6.2	1.5	1.8	3.4	1.2	1.3	2.5	2.1
+2.3 ft swl ; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	6.7	7.3	8.0	7.1	7.4	8.4	6.0	5.9	2.3	2.0	3.3	2.0	2.4	3.0	2.2
11	8	8.8	9.5	8.7	9.8	9.6	9.4	7.2	6.8	2.4	2.2	3.6	2.0	2.4	3.3	2.5
14	4	4.9	5.3	5.2	6.3	5.6	7.2	5.1	5.6	2.9	1.1	3.2	1.9	4.1	2.9	1.1
14	6	8.7	8.6	10.6	9.5	8.8	11.3	9.0	9.1	3.1	1.4	5.9	2.9	4.5	3.6	2.6
14	8	11.4	11.5	12.5	13.1	13.3	14.8	11.2	8.1	2.1	1.5	7.0	2.2	2.6	3.2	2.5
16	4	6.8	7.5	9.7	4.7	5.6	6.4	3.9	4.2	2.3	1.6	2.0	1.4	2.4	2.2	1.8
16	6	10.6	11.8	14.0	8.0	10.2	10.0	8.1	7.9	3.6	2.3	3.3	2.0	3.2	3.3	1.9
16	8	13.4	15.8	11.3	13.7	13.5	10.9	7.8	7.3	3.7	2.2	4.0	1.8	3.4	2.7	2.1
18	4	8.1	7.5	11.1	6.5	6.5	9.0	9.8	6.9	1.2	1.9	4.1	1.1	1.7	2.4	1.6
18	6	11.6	12.5	10.5	9.9	10.0	11.5	9.7	7.0	1.6	1.9	5.3	1.0	1.7	2.8	2.1
18	8	16.4	16.1	9.5	16.3	14.5	8.0	7.1	6.1	1.9	1.8	4.7	1.3	1.7	2.7	3.5

(Sheet 1 of 3)

Table 1 (Continued)

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 180-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	6.8	7.7	7.3	6.1	6.2	7.0	5.3	5.0	1.8	1.5	1.7	1.4	1.7	2.3	2.0
11	8	8.7	9.8	7.7	8.4	7.5	8.2	6.8	5.8	2.0	1.7	1.9	1.5	1.9	2.7	2.4
14	4	5.5	6.2	8.2	4.6	4.7	6.6	4.3	3.7	1.6	1.0	1.5	0.8	2.1	1.9	1.9
14	6	9.6	10.9	11.3	7.5	8.3	9.9	7.2	6.2	1.9	0.9	2.0	0.9	2.7	2.5	2.5
14	8	13.0	13.6	12.0	10.3	10.9	9.6	9.8	5.8	1.8	1.1	2.4	1.3	2.9	2.4	2.9
16	4	5.2	6.1	9.0	4.9	5.1	6.9	4.7	4.4	1.8	2.6	2.9	1.8	1.2	2.2	1.6
16	6	7.9	10.3	10.2	7.5	8.6	11.1	8.7	7.5	2.6	2.1	2.8	1.0	2.1	2.3	2.9
16	8	12.2	13.4	8.5	10.6	13.7	11.7	11.6	7.1	2.5	2.0	2.4	1.4	2.3	2.9	2.9
18	4	5.3	6.6	8.7	5.9	6.2	7.6	4.3	4.1	1.0	1.1	1.9	0.4	1.0	1.8	1.3
18	6	7.7	9.8	11.9	9.3	10.3	11.4	8.0	5.0	1.2	1.3	2.1	0.6	1.3	1.9	2.8
18	8	12.8	13.2	11.2	13.6	14.3	11.9	8.1	5.2	1.2	1.6	2.3	0.8	1.4	2.0	2.6
+2.3 ft swl;180-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	7.7	8.8	8.0	7.1	7.2	8.0	6.1	5.7	2.1	1.6	2.9	1.7	2.1	2.8	2.4
11	8	9.1	10.1	8.4	8.7	8.6	9.0	7.2	6.1	2.2	1.7	3.4	1.8	2.2	3.0	2.8
14	4	5.4	6.3	7.3	4.8	5.3	5.9	3.4	3.3	1.4	0.5	1.8	0.9	1.6	1.6	0.9
14	6	8.6	10.8	10.8	7.6	7.9	8.9	6.8	5.8	2.3	1.0	4.2	1.7	2.7	2.4	1.9
14	8	12.9	12.6	12.7	10.3	11.1	10.9	8.8	6.8	2.1	1.1	5.2	1.9	2.1	2.4	2.8
16	4	4.6	4.7	7.4	5.2	5.5	6.4	5.8	6.9	3.1	1.7	2.7	1.4	3.0	3.2	2.4
16	6	7.8	10.6	10.7	7.5	9.3	11.5	10.1	9.5	3.4	1.9	3.4	1.7	3.4	2.5	3.0
16	8	11.9	13.3	9.8	9.9	11.9	12.5	12.5	9.5	3.6	1.9	3.3	1.7	3.3	3.2	3.3
18	4	5.4	6.3	7.6	5.9	5.8	7.0	4.4	4.3	0.8	1.0	1.9	0.6	1.2	2.2	1.5
18	6	9.4	11.9	13.6	8.5	8.9	11.2	7.8	5.7	1.1	1.3	3.4	1.4	1.6	2.0	3.8
18	8	13.1	12.8	13.2	14.1	13.5	13.5	8.2	5.8	1.3	1.4	3.4	1.2	1.6	2.1	4.4

(Sheet 2 of 3)

Table 1 (Concluded)

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 215-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	5.1	5.3	6.1	5.3	6.3	6.3	4.6	4.9	1.6	1.3	2.3	1.3	1.5	2.1	2.6
11	8	6.6	7.2	6.9	7.2	8.7	7.7	5.8	5.6	1.7	1.4	2.9	1.4	1.6	2.4	3.1
14	4	3.3	4.5	4.7	3.9	4.4	4.7	4.9	6.4	1.7	1.0	1.2	0.9	2.4	2.4	3.7
14	6	6.9	7.0	8.8	6.5	8.3	8.5	9.1	7.3	1.9	0.8	2.0	0.8	2.7	2.9	4.4
14	8	9.1	10.6	10.2	9.2	10.8	9.0	8.8	8.9	1.9	0.9	3.0	1.0	3.3	3.5	4.3
16	4	3.6	3.9	5.7	4.7	4.6	5.1	4.7	4.4	1.6	1.7	3.5	1.1	0.9	1.9	2.4
16	6	6.1	7.3	9.4	7.4	8.5	10.8	6.0	6.7	1.9	1.6	3.9	0.8	1.7	2.3	3.9
16	8	8.5	9.7	7.4	9.8	13.0	13.4	7.3	6.0	1.9	1.6	3.6	0.9	1.5	2.6	3.4
18	4	6.1	5.9	7.1	4.6	6.2	7.7	6.4	5.3	1.3	1.1	1.8	0.5	1.1	2.5	2.3
18	6	9.4	10.1	12.5	8.1	11.2	11.2	9.2	6.0	1.0	1.1	2.1	0.8	1.1	2.2	2.5
18	8	13.3	15.6	10.4	12.6	16.9	10.4	7.6	5.6	1.4	1.5	2.5	0.8	1.3	2.4	1.9
+2.3 ft swl; 215-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	5.1	5.3	6.3	5.4	5.4	6.5	4.7	5.4	1.8	1.4	2.2	1.5	1.9	2.5	3.0
11	8	6.8	7.2	7.7	7.3	7.2	8.3	6.3	6.4	1.9	1.6	2.5	1.7	2.1	2.9	3.5
14	4	4.4	4.0	5.0	4.4	4.5	5.3	5.9	5.8	2.3	0.6	3.2	1.6	2.4	2.3	2.4
14	6	6.5	6.7	8.2	6.5	6.5	8.4	9.7	7.7	2.1	0.8	3.4	1.9	2.5	2.5	3.8
14	8	9.0	10.2	11.1	8.9	8.4	9.3	9.6	9.3	2.4	1.1	3.8	2.2	2.8	2.7	4.7
16	4	3.9	4.0	3.9	4.9	4.1	5.4	4.4	6.7	2.4	1.1	1.6	1.4	2.6	2.1	2.2
16	6	6.4	7.8	10.9	6.3	6.5	10.2	6.8	7.2	2.3	1.3	1.8	1.8	2.6	1.9	4.2
16	8	8.6	9.5	9.8	9.3	10.7	12.4	9.4	6.6	2.0	1.3	1.9	2.0	2.7	2.1	3.6
18	4	5.7	5.6	7.6	4.3	4.9	6.3	5.7	5.2	1.2	1.5	2.5	1.0	1.6	2.3	2.5
18	6	8.3	9.4	12.5	7.8	8.9	11.0	9.7	6.5	1.6	1.3	2.5	1.4	1.6	2.7	4.3
18	8	13.3	14.7	13.1	12.5	12.8	12.7	9.2	5.9	2.0	1.3	1.8	1.8	1.8	3.1	2.9

(Sheet 3 of 3)

Table 2
Wave Heights for Alternative 1

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.4	7.0	6.9	7.1	6.8	7.4	6.3	3.3	1.3	1.3	2.2	1.6	1.4	1.5	2.3
11	8	8.0	8.6	7.5	9.6	8.9	8.3	7.5	4.0	1.6	1.6	3.2	2.0	1.6	1.6	2.9
14	4	5.9	6.3	7.9	6.9	8.8	10.4	5.7	3.8	0.8	1.1	1.1	0.6	1.1	1.4	2.2
14	6	9.6	11.6	9.4	10.6	11.7	12.7	9.1	5.4	1.1	1.6	1.5	0.7	1.3	1.6	3.3
14	8	12.0	14.0	9.6	13.5	15.2	12.7	11.0	6.3	1.1	1.5	1.8	0.9	1.3	1.6	3.8
16	4	6.0	7.7	10.1	5.9	7.4	9.8	7.7	4.3	1.0	1.4	2.6	0.4	0.3	1.1	2.7
16	6	11.7	14.8	8.9	10.1	10.4	10.6	10.3	5.0	1.1	1.7	3.2	0.4	0.3	1.1	2.8
16	8	15.1	16.8	9.5	14.6	15.0	10.2	7.8	4.8	1.3	2.1	3.6	0.4	0.4	1.2	2.9
18	4	6.9	8.7	9.6	8.4	9.5	10.4	9.3	4.6	1.4	2.5	2.4	0.6	0.7	1.3	2.5
18	6	11.3	14.6	8.4	12.7	14.2	7.7	8.3	4.7	1.2	2.0	2.5	0.7	0.9	1.3	2.8
18	8	17.2	14.9	7.8	18.3	12.4	7.5	7.2	4.8	1.3	2.5	3.1	1.1	1.3	1.6	2.7
+2.3 ft swl; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.6	7.2	7.3	6.9	6.9	7.8	6.5	3.4	1.3	1.3	1.8	1.6	1.5	1.5	2.5
11	8	8.5	9.1	8.2	9.6	9.2	8.7	7.8	4.2	1.7	1.6	2.3	1.9	1.7	1.7	3.0
14	4	6.2	6.4	6.4	6.8	7.3	9.7	5.6	4.6	0.9	1.0	2.1	0.8	1.3	1.7	2.6
14	6	9.0	8.9	10.5	10.3	11.6	12.1	8.6	6.1	1.2	1.2	3.8	1.0	1.7	2.2	3.6
14	8	11.5	12.6	11.1	12.6	13.8	13.8	12.0	7.6	1.5	1.4	3.6	1.1	1.7	2.0	4.7
16	4	6.0	7.6	10.5	6.4	8.0	8.7	7.7	4.7	1.2	2.0	2.1	0.4	0.3	1.2	2.6
16	6	11.5	13.2	10.6	11.5	12.4	12.3	10.7	5.2	1.4	2.4	2.8	0.5	0.4	0.9	3.2
16	8	14.6	16.8	11.5	15.0	16.1	11.2	8.6	5.1	1.5	2.4	3.0	0.5	0.5	1.2	2.6
18	4	8.4	8.9	11.0	6.5	6.7	9.1	10.3	5.1	1.5	2.4	2.1	1.2	1.4	1.7	2.4
18	6	12.0	13.0	8.6	11.6	11.7	11.1	9.0	4.9	1.5	2.0	2.5	1.3	1.6	1.4	2.6
18	8	15.9	16.2	8.2	18.4	13.1	8.0	7.8	4.3	1.7	1.7	2.3	1.6	1.8	1.5	2.8

(Sheet 1 of 3)

Table 2 (Continued)

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 180-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.4	6.9	7.0	6.0	6.1	7.2	5.3	2.7	0.9	0.7	1.4	1.4	1.2	1.4	1.5
11	8	8.4	9.0	7.5	7.8	7.9	8.1	6.1	3.3	1.0	0.9	2.0	1.9	1.4	1.6	1.8
14	4	4.9	4.8	7.2	5.0	4.7	7.2	8.0	3.5	0.6	0.8	0.7	0.5	0.8	1.2	1.9
14	6	7.6	8.5	10.3	7.9	8.5	10.4	7.8	4.3	0.8	1.0	1.1	0.6	1.0	1.4	2.2
14	8	11.7	12.5	11.2	10.7	11.3	9.8	6.7	4.5	0.7	0.9	1.1	0.6	1.2	1.7	2.4
16	4	4.3	4.7	6.8	4.5	5.6	6.2	6.0	4.6	0.8	1.3	1.6	0.3	0.3	1.1	2.5
16	6	8.0	9.4	8.9	8.5	10.1	11.0	8.8	5.3	1.0	1.9	2.1	0.4	0.4	1.6	2.9
16	8	10.9	13.6	7.1	11.2	11.9	11.5	9.3	5.9	1.1	2.0	2.1	0.5	0.4	1.7	2.9
18	4	4.9	6.2	8.4	5.2	5.2	7.4	4.9	3.7	0.6	1.6	2.1	0.5	0.8	1.5	2.2
18	6	6.7	8.7	10.8	9.0	9.7	10.8	8.3	4.2	1.3	2.4	3.6	0.8	1.2	2.0	2.4
18	8	11.3	13.2	12.1	14.0	14.3	11.4	7.2	4.8	1.4	2.5	4.0	1.0	1.3	2.0	2.7
+2.3 ft swl; 180-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.7	7.3	7.4	6.2	5.3	7.5	5.5	2.9	1.0	0.9	1.4	1.5	1.4	1.5	1.7
11	8	8.8	9.6	8.1	8.1	8.4	8.9	6.4	3.6	1.3	1.2	1.8	2.2	1.8	1.7	2.2
14	4	4.6	5.3	6.2	5.1	5.8	6.2	7.6	4.1	0.9	0.8	2.8	0.5	1.2	1.8	2.7
14	6	7.3	9.2	9.0	7.9	8.6	9.3	10.1	5.5	1.0	0.9	2.8	0.7	1.4	1.8	3.3
14	8	10.9	12.8	12.2	10.8	11.6	11.0	8.8	5.8	1.0	1.0	2.2	0.9	1.6	1.5	3.7
16	4	4.3	4.9	4.8	5.3	6.2	6.7	6.3	3.8	1.0	1.8	2.1	0.2	0.3	1.2	2.2
16	6	6.1	7.2	9.0	8.5	10.2	12.0	9.2	5.8	1.3	2.8	3.1	0.3	0.5	1.3	3.8
16	8	11.1	12.0	8.8	11.6	12.6	12.4	10.2	6.6	1.5	2.9	3.1	0.4	0.5	1.6	3.8
18	4	4.2	5.6	6.5	6.2	6.4	7.8	4.9	3.2	0.7	1.7	2.1	1.3	1.5	1.5	1.5
18	6	8.2	9.0	12.1	8.9	10.1	11.3	9.9	4.4	1.1	2.4	3.3	2.0	2.2	2.2	2.2
18	8	12.7	14.3	14.5	15.2	15.2	14.8	8.1	5.4	1.5	2.3	3.2	1.9	2.0	2.3	2.4

(Sheet 2 of 3)

Table 2 (Concluded)

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 215-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	4.9	5.1	5.8	5.2	5.5	6.1	4.0	1.5	0.5	0.6	0.7	1.2	0.9	0.9	0.9
11	8	7.1	7.5	6.9	7.4	7.5	7.5	4.8	1.8	0.7	0.7	1.0	1.7	1.3	1.1	1.2
14	4	4.2	4.9	6.5	4.7	4.5	5.6	3.7	2.3	0.2	0.3	0.3	0.4	0.6	1.1	1.0
14	6	6.2	7.8	9.2	7.8	7.5	8.6	6.6	2.6	0.4	0.7	0.7	0.4	0.7	1.4	1.4
14	8	9.7	11.5	11.1	11.2	10.0	9.2	6.3	3.1	0.6	0.8	1.1	0.6	0.8	1.6	1.8
16	4	2.8	2.5	3.5	4.4	4.8	4.7	6.4	3.3	0.3	0.9	2.1	0.2	0.2	1.3	1.3
16	6	5.6	8.5	9.6	6.5	6.4	8.0	8.0	3.8	0.4	0.9	2.2	0.3	0.3	1.3	1.6
16	8	8.0	9.1	9.2	9.6	10.3	12.3	7.9	4.4	0.8	1.4	2.7	0.4	0.3	1.3	2.1
18	4	5.4	6.4	7.6	4.6	5.1	8.8	5.2	3.0	0.7	1.4	1.5	0.6	0.8	1.4	2.0
18	6	7.9	9.7	11.0	7.7	9.1	11.8	6.3	3.4	0.8	1.8	1.9	0.7	0.9	1.5	2.2
18	8	10.4	12.9	11.0	11.8	12.7	9.4	6.1	4.1	1.0	2.2	2.5	0.8	0.9	1.7	2.3
+2.3 ft swl; 215-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	4.9	5.0	5.6	5.4	5.6	6.4	4.1	1.6	0.6	0.5	0.8	1.3	0.9	1.0	1.0
11	8	6.9	7.3	7.2	7.4	7.5	8.0	5.0	1.9	0.8	0.7	1.0	1.8	1.2	1.2	1.2
14	4	4.4	4.9	5.2	4.6	4.3	4.9	4.1	2.3	0.5	0.5	1.3	0.4	0.9	1.3	1.3
14	6	6.0	6.2	7.6	6.7	6.0	6.7	7.3	3.5	0.7	0.5	1.4	0.5	1.1	2.1	1.8
14	8	10.1	11.2	12.3	10.3	9.6	10.7	7.4	3.7	0.7	0.7	2.0	0.6	1.0	2.3	1.9
16	4	2.9	3.3	4.0	5.0	4.9	6.0	5.3	3.4	0.9	1.3	1.8	0.2	0.2	1.3	1.4
16	6	5.6	6.6	8.9	6.7	6.8	7.9	8.3	4.2	1.1	1.5	2.2	0.2	0.3	1.6	1.8
16	8	7.5	8.7	9.5	9.7	10.0	13.3	8.7	5.4	1.1	1.7	2.0	0.3	0.4	1.5	2.3
18	4	6.1	6.1	6.3	4.4	6.6	8.7	5.1	3.1	0.5	1.5	2.0	1.3	1.6	1.5	1.2
18	6	9.1	9.0	10.1	8.0	11.5	13.8	6.5	3.0	0.6	1.4	1.9	1.3	1.6	1.6	1.6
18	8	10.4	10.8	11.9	11.9	13.6	12.6	6.5	3.4	0.7	1.8	2.4	1.4	1.7	1.8	1.8

(Sheet 3 of 3)

Table 3
Wave Heights for Alternative 1a

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.7	7.1	7.1	7.0	7.0	7.3	6.4	3.7	1.2	1.2	1.1	1.5	1.3	1.0	2.0
11	8	8.5	9.0	7.8	9.9	9.2	8.3	7.4	4.4	1.4	1.4	1.2	1.9	1.5	1.2	2.5
14	4	5.8	6.6	8.4	6.8	9.0	10.3	5.7	4.3	0.8	1.0	0.8	0.4	0.9	1.0	1.9
14	6	8.8	9.7	11.1	10.8	12.7	12.2	9.4	5.8	1.0	1.3	1.0	0.5	1.0	1.2	2.7
14	8	12.0	14.4	10.3	13.6	15.9	13.2	11.3	6.3	1.3	1.6	1.3	0.7	1.2	1.2	3.5
16	4	6.4	8.0	10.4	6.7	8.2	10.5	6.9	4.5	0.9	0.9	1.2	0.2	0.2	0.7	2.0
16	6	11.6	14.8	9.6	9.9	10.7	11.1	10.1	5.3	1.3	1.4	1.3	0.3	0.3	0.7	2.6
16	8	16.7	17.5	10.5	14.9	15.2	10.3	7.4	4.9	1.4	1.7	1.5	0.3	0.4	1.1	2.3
18	4	7.4	8.8	9.8	7.6	8.5	8.9	9.4	5.1	0.9	1.6	1.2	0.5	0.6	0.9	2.4
18	6	11.6	15.3	8.1	12.0	14.2	7.9	8.1	4.5	1.0	1.7	1.3	0.6	0.8	1.0	2.4
18	8	16.9	16.3	8.2	18.8	12.3	7.6	7.1	4.8	0.9	1.8	1.2	0.8	1.0	1.0	2.3
+2.3 ft swl; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.4	6.9	7.4	7.4	7.3	7.9	6.4	3.7	1.2	1.3	1.5	1.5	1.2	1.0	2.1
11	8	8.6	9.1	8.2	9.8	9.2	8.7	7.9	4.6	1.5	1.5	1.9	1.9	1.5	1.2	2.6
14	4	6.3	6.1	6.9	6.9	7.2	9.7	5.3	4.3	0.9	1.0	1.9	0.8	1.3	1.0	2.6
14	6	9.4	9.3	10.1	10.5	11.3	12.1	8.6	6.8	1.1	1.1	2.6	1.0	1.7	1.1	3.6
14	8	11.7	12.5	11.7	13.1	15.0	13.2	12.2	7.8	1.2	1.2	2.6	1.1	1.6	1.1	4.7
16	4	6.1	7.7	10.5	6.1	8.1	8.6	7.2	4.6	1.0	1.9	2.2	0.3	0.2	0.7	2.3
16	6	11.2	13.0	12.3	11.3	13.4	11.5	10.2	5.0	1.0	2.3	2.6	0.4	0.4	0.6	2.9
16	8	14.6	17.0	11.7	15.7	16.5	11.7	8.3	5.0	1.1	2.4	3.0	0.5	0.5	0.7	2.5
18	4	7.8	7.8	10.4	7.9	8.2	9.6	8.9	5.0	1.1	2.1	2.2	1.3	1.5	1.1	2.0
18	6	12.6	13.2	9.2	13.3	12.6	9.9	8.9	5.2	1.3	1.8	2.2	1.5	1.7	0.8	2.3
18	8	14.1	16.9	8.5	17.9	13.7	8.0	8.0	5.2	1.5	1.5	1.7	1.6	1.7	1.3	2.2

(Sheet 1 of 2)

Table 3 (Concluded)

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 180-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.6	7.3	7.0	6.1	6.1	7.0	5.1	2.9	0.8	0.7	0.9	1.4	1.0	0.8	1.4
11	8	8.0	9.0	7.2	7.9	8.0	7.9	5.9	3.4	1.0	0.8	1.0	1.8	1.3	0.9	1.6
14	4	4.6	5.0	7.4	4.5	5.1	7.4	6.7	3.1	0.7	0.8	0.8	0.4	0.7	0.7	1.6
14	6	8.4	9.5	10.6	6.5	6.8	10.0	8.3	4.3	0.9	1.0	1.1	0.4	0.8	0.6	1.9
14	8	10.8	12.3	9.9	10.8	11.1	10.0	6.8	4.5	0.9	1.0	1.3	0.5	0.9	1.0	2.0
16	4	4.5	5.3	6.6	4.7	5.9	6.4	5.8	3.7	0.7	0.9	1.5	0.2	0.2	0.7	1.7
16	6	8.3	10.3	9.8	8.9	10.4	11.6	9.2	5.2	1.2	1.4	2.4	0.4	0.3	1.1	2.5
16	8	12.0	15.1	7.4	12.8	14.2	11.2	9.0	6.1	1.4	1.8	2.9	0.4	0.4	1.2	2.6
18	4	4.6	5.4	7.5	6.0	6.1	7.9	4.7	3.0	0.7	1.1	1.2	0.5	0.6	0.9	1.7
18	6	7.8	9.6	12.6	8.6	9.0	10.8	8.0	4.0	0.9	1.4	1.6	0.8	0.9	1.1	1.8
18	8	11.8	14.3	11.1	15.1	15.0	10.0	6.7	4.5	0.8	1.6	1.8	0.7	0.8	1.3	2.1
+2.3 ft swl; 180-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.5	7.1	7.5	6.4	6.3	7.4	5.3	3.0	0.9	0.9	1.3	1.2	1.0	0.9	1.4
11	8	8.6	9.3	8.2	8.1	8.3	8.6	6.5	3.7	1.1	1.0	1.7	1.7	1.3	1.1	1.8
14	4	4.9	5.7	4.9	4.6	5.8	6.6	7.5	4.5	0.9	1.3	2.1	0.6	0.8	1.0	2.0
14	6	7.7	9.0	8.5	6.9	8.9	9.8	10.7	5.1	0.8	1.1	1.3	0.7	1.1	0.9	2.7
14	8	11.9	12.8	12.1	10.6	11.3	11.6	9.1	5.8	0.7	1.0	1.2	0.8	1.2	1.0	3.3
16	4	4.9	5.4	5.8	5.6	6.5	7.7	5.9	3.6	1.1	1.7	2.5	0.2	0.2	0.8	2.1
16	6	7.3	8.5	10.5	8.7	10.6	12.2	8.7	4.8	1.3	2.4	3.1	0.4	0.3	1.0	2.8
16	8	11.8	13.2	9.0	12.5	14.9	12.6	9.6	6.3	1.4	2.6	3.5	0.4	0.4	1.2	3.0
18	4	5.4	5.8	7.9	6.0	6.3	8.0	5.1	3.4	0.6	1.4	1.6	1.1	1.3	1.1	1.6
18	6	8.4	9.3	14.0	9.4	10.1	11.9	9.1	4.3	0.9	1.6	1.9	1.6	1.8	1.3	1.8
18	8	12.8	14.3	13.8	15.7	16.0	13.6	7.4	5.3	1.0	1.8	2.3	1.3	1.5	1.6	1.9

(Sheet 2 of 2)

Table 4
Wave Heights for Alternative 1b

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.3	6.8	7.0	7.1	7.2	7.3	6.0	3.7	1.0	1.0	1.5	0.5	1.2	0.9	2.0
11	8	8.3	8.7	7.7	9.7	9.3	8.2	7.3	4.4	1.3	1.3	1.9	2.0	1.5	1.1	2.5
14	4	5.9	6.4	8.5	6.7	8.3	9.7	6.3	4.2	0.8	1.0	1.2	0.4	0.8	0.9	1.7
14	6	8.0	8.9	10.6	10.7	12.8	11.8	9.4	5.7	1.1	1.3	1.5	0.6	1.1	1.2	2.5
14	8	11.5	14.1	9.3	13.7	15.6	12.7	10.6	6.1	1.2	1.4	1.6	0.6	1.1	1.1	3.0
16	4	6.7	8.6	10.7	5.7	6.9	8.5	6.9	3.6	0.8	1.1	1.8	0.3	0.2	0.6	1.8
16	6	10.8	13.8	9.2	11.1	11.8	11.0	9.2	4.3	1.1	1.2	2.2	0.3	0.3	0.5	2.3
16	8	15.6	17.0	9.8	15.1	15.5	9.8	7.4	4.8	1.3	1.8	3.2	0.4	0.3	0.6	2.4
18	4	6.9	8.2	10.3	7.6	8.7	9.9	9.5	4.5	1.0	1.6	1.8	0.5	0.7	0.5	2.5
18	6	9.6	13.0	8.1	12.6	14.7	7.4	7.8	4.3	0.8	1.9	2.3	0.7	0.8	0.6	2.5
18	8	16.1	16.1	8.0	17.9	12.4	7.2	7.7	4.8	0.9	1.8	2.3	0.9	1.0	1.1	2.4
+2.3 ft swl; 160-deg azimuth																
Period Sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.4	7.1	7.3	7.2	7.3	7.9	6.4	3.8	1.1	1.1	1.5	1.4	1.1	0.9	2.1
11	8	8.8	9.4	8.2	9.5	9.3	8.7	7.7	4.5	1.3	1.3	1.9	1.8	1.4	1.1	2.6
14	4	6.1	5.7	6.1	6.4	6.9	9.3	5.1	4.6	1.0	0.8	1.9	0.7	1.1	1.0	1.9
14	6	10.0	8.8	10.8	9.8	10.1	12.5	10.2	6.7	1.1	1.1	2.7	0.9	1.4	1.1	0.4
14	8	11.7	12.5	11.1	12.7	14.5	13.7	12.0	6.9	1.2	1.2	2.9	1.0	1.5	1.3	3.4
16	4	6.1	8.0	10.7	6.4	8.2	8.6	7.2	4.3	1.0	1.7	2.0	0.3	0.3	0.7	2.3
16	6	11.4	13.0	11.6	11.3	13.1	12.7	10.1	4.6	1.0	1.9	2.5	0.4	0.4	0.6	2.8
16	8	14.8	16.8	11.0	15.3	16.3	10.5	8.0	4.5	1.1	2.2	3.0	0.5	0.5	0.6	2.5
18	4	7.4	7.7	10.2	8.5	8.4	10.2	8.6	5.0	0.8	1.9	2.2	1.1	1.4	0.9	2.3
18	6	12.2	13.5	8.8	12.3	12.1	10.5	8.9	5.2	1.1	1.8	2.2	1.3	1.5	0.6	2.3
18	8	15.2	16.5	8.4	17.5	13.2	8.1	7.8	5.2	1.3	1.4	2.0	1.5	1.6	0.9	2.3

Table 5
Wave Heights for Alternative 1c

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.4	7.1	7.2	7.2	7.3	8.0	4.9	3.4	1.1	1.1	1.3	1.4	1.2	0.9	1.8
11	8	8.5	9.2	7.9	9.5	9.3	8.7	5.7	4.1	1.3	1.3	1.5	1.9	1.5	1.1	2.2
14	4	5.8	6.5	8.7	7.4	9.3	10.4	4.6	3.6	0.7	1.0	1.0	0.4	0.7	0.9	1.8
14	6	7.3	9.3	11.4	12.3	14.4	11.9	6.6	4.8	1.0	1.3	1.2	0.5	0.9	0.9	2.5
14	8	10.6	12.2	11.9	15.2	17.7	11.5	8.3	5.6	1.1	1.5	1.1	0.6	1.0	1.1	3.1
16	4	6.5	7.5	10.5	6.5	7.5	9.8	6.1	4.3	0.9	1.1	1.7	0.3	0.3	0.6	2.0
16	6	11.1	13.8	10.1	11.6	12.4	11.6	7.1	4.6	1.2	1.2	1.8	0.3	0.4	0.6	2.2
16	8	15.0	16.6	10.1	16.0	16.3	10.1	6.9	5.0	1.2	1.6	1.7	0.4	0.4	0.8	2.1
18	4	7.1	8.5	10.2	7.6	8.4	9.4	7.2	4.3	0.8	2.0	1.6	0.5	0.8	1.0	2.2
18	6	11.2	14.4	7.5	11.6	13.1	8.1	6.4	4.5	1.0	2.0	1.6	0.7	0.9	1.0	2.4
18	8	16.5	15.6	7.8	18.0	12.3	7.2	6.3	4.8	1.0	2.2	0.7	0.9	1.0	1.2	2.2
+2.3 ft swl; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.5	7.4	7.7	7.3	7.9	8.7	4.8	3.3	1.1	1.2	1.9	1.4	1.2	1.0	1.8
11	8	8.7	9.7	8.3	9.0	9.7	9.0	5.9	3.9	1.3	1.4	1.6	1.8	1.4	1.1	2.2
14	4	5.5	6.0	6.7	7.4	8.1	9.4	3.7	3.5	0.9	0.9	1.3	0.6	0.9	0.8	1.9
14	6	8.2	9.2	10.2	10.6	11.3	12.3	6.9	6.2	1.0	1.1	1.7	0.8	1.0	0.8	3.1
14	8	10.7	11.6	12.6	13.2	15.1	13.1	8.8	6.9	1.0	1.1	2.2	0.9	1.3	0.9	4.2
16	4	6.0	8.3	10.6	6.3	7.5	8.1	5.6	4.0	0.7	1.7	2.0	0.2	0.2	0.5	2.2
16	6	10.7	12.6	11.3	11.2	13.0	12.3	7.4	5.2	1.1	2.2	2.5	0.4	0.4	0.6	2.8
16	8	14.9	16.5	10.9	15.6	16.6	10.7	7.2	5.1	1.1	2.3	2.6	0.4	0.5	0.7	2.4
18	4	7.0	7.1	9.7	7.6	6.6	9.2	6.5	4.2	1.1	1.4	1.5	1.5	1.4	0.9	1.8
18	6	10.9	12.4	9.4	12.5	11.4	11.0	7.4	4.7	1.3	1.6	1.8	1.5	1.4	1.1	2.2
18	8	14.8	16.4	8.5	17.4	14.3	8.3	6.6	4.9	1.4	1.3	1.5	1.4	1.5	1.3	2.0

(Sheet 1 of 2)

Table 5 (Concluded)

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
									+1.0 ft swl; 180-deg azimuth							
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.9	7.8	7.5	6.1	6.6	7.5	3.9	2.6	0.7	0.6	0.8	1.6	1.0	0.8	1.0
11	8	9.3	10.0	7.9	8.0	8.6	8.3	4.7	3.1	0.9	0.7	1.0	1.9	1.4	0.9	1.3
14	4	5.4	5.3	7.0	5.4	5.5	7.7	5.4	2.9	0.4	0.7	0.5	0.3	0.4	0.6	1.4
14	6	8.4	9.0	9.4	8.6	8.9	10.7	5.8	3.9	0.6	0.9	0.8	0.3	0.6	0.8	1.6
14	8	11.6	12.7	11.1	11.6	12.1	8.8	5.6	3.9	0.7	1.0	1.0	0.5	0.7	1.0	1.6
16	4	4.5	5.6	7.8	5.5	5.8	7.2	4.7	3.3	0.5	0.7	1.0	0.2	0.2	0.8	1.3
16	6	7.6	9.4	9.1	9.0	10.3	10.2	7.2	4.4	0.7	0.9	1.6	0.3	0.3	1.1	1.5
16	8	11.1	14.2	7.3	12.8	13.2	9.7	7.4	5.4	1.0	1.2	2.0	0.4	0.3	1.3	1.8
18	4	5.3	6.3	8.3	5.9	5.0	7.1	3.8	2.5	0.6	0.9	1.0	0.4	0.5	0.8	1.5
18	6	8.2	10.6	12.3	10.1	9.5	11.5	5.8	3.1	0.8	1.0	1.2	0.6	0.6	0.9	1.6
18	8	12.1	15.0	11.4	15.0	14.4	10.5	5.8	4.4	1.0	1.4	1.6	0.7	0.8	1.1	2.1
									+2.3 ft swl; 180-deg azimuth							
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	7.0	7.8	7.5	6.2	6.5	7.1	4.0	2.5	0.7	0.5	1.0	1.2	0.9	0.8	1.0
11	8	8.9	9.5	8.0	8.4	8.7	8.4	4.8	3.1	0.9	0.7	1.3	1.7	1.3	1.0	1.4
14	4	4.6	5.6	7.1	4.7	5.9	6.2	7.6	3.8	0.9	0.7	1.6	0.6	1.0	0.7	2.5
14	6	6.9	8.6	9.2	8.5	8.9	8.9	6.7	4.9	0.8	0.5	2.0	0.7	1.1	0.7	2.6
14	8	10.5	12.6	12.1	11.3	12.3	10.6	6.7	5.2	0.9	0.7	2.2	0.9	1.4	1.1	3.0
16	4	4.4	4.9	5.6	5.9	6.0	7.5	5.2	3.5	0.8	1.4	2.2	0.2	0.2	0.6	1.9
16	6	6.7	8.1	10.2	9.7	11.6	12.0	7.4	5.1	1.1	1.8	3.1	0.3	0.3	0.9	2.3
16	8	12.6	14.6	9.1	13.1	14.7	12.5	8.1	6.0	1.1	2.3	3.4	0.5	0.4	1.2	2.4
18	4	5.0	5.7	7.1	6.1	5.5	6.9	4.3	2.6	0.5	1.1	1.5	1.0	1.2	1.0	1.1
18	6	8.7	9.8	13.4	8.8	8.6	10.6	6.7	3.8	0.7	1.2	1.8	1.2	1.4	1.3	1.5
18	8	12.5	14.9	13.2	14.0	12.3	14.7	6.6	5.2	0.9	1.3	2.1	1.2	1.4	1.5	1.8

(Sheet 2 of 2)

Table 6
Wave Heights for Alternative 1d

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.3	6.9	6.9	7.2	7.7	7.8	3.8	3.1	0.9	1.0	1.2	1.5	1.1	0.9	1.4
11	8	8.8	9.6	7.8	9.4	9.5	8.4	4.5	3.7	1.1	1.2	1.6	1.9	1.4	1.1	1.8
14	4	5.6	6.5	8.2	7.9	9.1	10.5	3.2	2.9	0.5	0.9	0.9	0.3	0.6	0.6	1.4
14	6	8.8	9.9	11.0	11.9	13.6	11.8	5.9	5.0	0.9	1.3	1.2	0.5	0.8	0.9	2.3
14	8	10.6	12.6	11.1	16.7	18.1	9.4	6.8	5.2	0.9	1.3	1.3	0.6	0.8	0.9	2.2
16	4	6.7	7.5	9.6	6.6	6.7	8.4	4.9	4.1	0.6	0.8	1.5	0.2	0.2	0.7	1.2
16	6	10.5	12.0	8.3	11.9	12.1	11.2	6.6	5.1	0.8	1.1	2.0	0.4	0.4	0.9	2.0
16	8	13.7	16.4	9.7	17.2	14.8	9.3	7.1	5.5	1.1	1.3	2.5	0.4	0.4	0.9	2.3
18	4	6.5	9.1	9.1	6.9	7.2	9.2	6.2	4.3	0.8	1.4	1.2	0.3	0.4	1.0	1.9
18	6	9.4	12.6	7.5	13.3	14.2	7.7	6.0	4.9	0.9	1.3	1.4	0.4	0.6	1.1	2.1
18	8	16.0	14.8	7.3	18.1	10.5	6.9	6.2	4.9	0.9	1.5	1.8	0.6	0.7	0.9	2.0
+2.3 ft swl; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.5	7.0	7.5	7.4	7.9	8.5	4.0	3.1	1.0	1.1	1.3	1.4	1.1	0.9	1.5
11	8	9.0	9.7	8.6	9.6	9.7	9.3	5.0	3.9	1.3	1.4	1.9	1.8	1.5	1.1	2.0
14	4	6.3	6.4	6.5	7.8	7.4	9.1	3.6	3.4	0.8	0.9	1.7	0.7	1.0	0.7	2.1
14	6	8.9	10.0	11.1	11.1	11.0	12.2	6.5	6.3	1.0	1.1	2.2	0.9	1.3	0.8	3.5
14	8	11.8	12.2	12.7	14.2	15.4	12.7	8.0	7.2	1.1	1.2	2.8	1.0	1.3	1.0	4.1
16	4	6.4	8.6	10.7	6.4	6.3	8.5	5.4	4.3	0.8	1.3	2.2	0.2	0.2	0.5	1.6
16	6	10.6	12.6	11.1	10.7	10.8	11.9	6.6	5.4	1.1	2.1	3.0	0.4	0.4	0.6	2.9
16	8	13.7	16.3	11.5	16.3	16.1	12.1	7.1	6.0	1.2	2.1	3.0	0.4	0.5	0.7	2.5
18	4	7.1	9.0	11.0	7.1	7.6	9.9	6.2	4.5	0.9	2.0	2.1	0.8	1.0	1.2	2.5
18	6	11.0	12.9	8.3	11.5	13.4	11.1	6.6	5.3	1.1	2.0	2.3	0.9	1.1	1.3	2.3
18	8	15.3	16.2	8.0	18.2	13.3	8.2	6.4	5.0	1.3	1.8	2.5	1.2	1.3	1.1	1.9

Table 7
Wave Heights for Alternative 2a

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 180-deg azimuth																
Period sec	**Height ft**	**Gage 1**	**Gage 2**	**Gage 3**	**Gage 4**	**Gage 5**	**Gage 6**	**Gage 7**	**Gage 8**	**Gage 9**	**Gage 10**	**Gage 11**	**Gage 13**	**Gage 14**	**Gage 15**	**Gage 16**
8	6	6.8	7.4	7.0	6.3	6.4	7.3	5.1	2.8	0.9	0.8	1.0	1.5	0.9	0.8	1.4
11	8	8.4	9.1	7.4	8.0	8.3	8.2	5.9	3.4	1.1	0.9	1.3	1.7	1.1	1.0	1.6
14	4	5.5	5.5	8.0	4.4	4.6	7.2	7.1	3.6	0.5	0.8	0.7	0.2	1.2	0.6	1.6
14	6	8.6	9.7	10.4	7.9	8.2	10.8	7.2	4.3	0.7	1.0	0.9	0.4	1.5	0.6	1.7
14	8	12.5	14.0	10.8	11.2	11.7	8.4	6.0	4.1	0.6	1.0	1.0	0.4	1.3	0.9	1.7
16	4	4.8	5.5	7.4	4.3	5.5	6.2	6.1	4.3	0.8	1.0	1.8	0.1	1.4	0.6	1.8
16	6	7.9	10.0	9.2	8.4	9.8	10.7	9.7	5.2	1.1	1.3	2.5	0.3	1.9	0.8	2.2
16	8	12.2	15.4	7.1	12.4	13.4	11.1	8.9	5.5	1.2	1.6	2.9	0.3	1.9	1.1	2.0
18	4	5.0	5.9	7.7	5.6	5.6	7.9	4.4	2.8	0.5	1.1	1.1	0.3	1.3	0.6	1.4
18	6	7.8	9.1	11.4	9.8	10.0	11.5	7.5	3.5	0.6	1.4	1.5	0.5	1.7	0.8	1.6
18	8	11.5	13.6	11.9	15.2	14.8	10.8	6.4	4.2	0.8	1.6	1.7	0.7	1.7	1.1	1.9
+1.0 ft swl; 215-deg azimuth																
Period sec	**Height ft**	**Gage 1**	**Gage 2**	**Gage 3**	**Gage 4**	**Gage 5**	**Gage 6**	**Gage 7**	**Gage 8**	**Gage 9**	**Gage 10**	**Gage 11**	**Gage 13**	**Gage 14**	**Gage 15**	**Gage 16**
8	6	5.0	5.4	5.9	5.3	5.6	6.3	3.9	1.7	0.5	0.5	0.8	1.3	0.5	0.6	0.7
11	8	6.8	7.3	6.9	7.4	7.7	7.7	4.7	2.1	0.6	0.6	0.9	1.9	0.7	0.7	0.9
14	4	3.4	4.2	5.1	4.3	4.6	5.5	3.8	1.9	0.3	0.4	0.3	0.1	0.5	0.8	1.0
14	6	5.3	6.9	8.5	7.8	7.9	9.0	6.3	2.6	0.3	0.4	0.4	0.2	0.6	0.9	1.1
14	8	9.5	11.3	11.3	11.7	9.9	9.0	6.1	2.8	0.3	0.3	0.4	0.3	0.6	0.9	1.4
16	4	3.1	2.9	4.2	4.3	4.6	4.3	4.9	2.7	0.3	0.4	1.4	0.1	0.8	0.7	0.8
16	6	5.0	5.6	9.3	6.8	7.0	7.6	8.1	3.8	0.5	0.6	1.8	0.2	1.1	0.9	1.3
16	8	8.4	9.9	8.7	9.1	9.8	12.3	7.3	4.3	0.6	0.7	1.8	0.2	1.2	0.9	1.6
18	4	4.2	5.4	6.5	4.5	5.0	7.5	4.4	2.3	0.4	0.8	1.1	0.2	1.2	0.7	1.2
18	6	9.2	10.8	12.0	9.2	10.3	11.7	5.6	2.4	0.4	1.1	1.3	0.2	1.3	0.7	1.3
18	8	12.8	15.1	9.3	11.9	13.0	9.5	5.3	3.1	0.6	1.4	1.9	0.5	1.7	0.9	1.5

(Sheet 1 of 2)

Table 7 (Concluded)

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+2.3 ft swl; 215-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	5.3	5.6	6.2	5.6	5.9	6.7	3.9	1.8	0.5	0.4	0.8	1.4	0.6	0.7	0.7
11	8	6.8	7.3	7.3	7.4	7.7	8.0	4.8	2.2	0.7	0.5	1.1	2.0	0.8	0.9	1.0
14	4	4.1	4.8	5.1	4.7	4.4	4.2	3.3	1.6	0.2	0.1	0.2	0.2	0.5	1.0	1.0
14	6	6.1	7.3	9.2	7.6	7.0	7.3	6.2	2.9	0.4	0.2	0.8	0.3	0.8	1.3	1.6
14	8	9.1	11.2	12.3	11.6	9.6	10.7	6.7	3.6	0.5	0.4	1.2	0.3	1.0	1.4	1.8
16	4	3.1	4.1	5.8	4.7	3.5	4.4	4.7	2.8	0.7	1.0	2.4	0.0	0.9	0.7	1.1
16	6	5.1	6.3	10.1	7.5	6.3	8.2	8.0	4.0	0.8	1.1	2.5	0.1	1.1	0.9	1.3
16	8	7.8	10.1	10.1	10.3	10.2	12.9	7.8	4.9	0.8	1.2	2.4	0.3	1.3	1.0	1.5
18	4	6.0	6.9	7.3	4.9	5.7	8.9	3.7	2.4	0.4	1.2	1.8	0.6	1.0	0.9	0.8
18	6	8.8	8.4	10.4	8.0	10.2	12.9	6.0	3.0	0.5	1.3	2.0	0.8	1.0	1.0	1.3
18	8	13.3	14.9	13.3	12.9	14.7	14.7	5.8	3.4	0.5	1.4	2.3	0.9	1.3	1.1	1.2

(Sheet 2 of 2)

Table 8. Wave Heights for Alternative 3a

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.4	6.8	7.0	7.1	6.7	7.4	5.7	3.3	1.1	1.0	1.4	1.4	1.2	1.0	1.7
11	8	8.2	8.6	7.5	9.5	8.9	8.3	6.9	4.1	1.2	1.2	1.7	1.8	1.5	1.2	2.1
14	4	5.8	6.9	9.3	7.2	8.3	10.6	5.7	4.7	0.8	1.1	1.1	0.3	1.2	0.8	1.4
14	6	9.1	10.3	10.6	10.9	11.4	12.0	9.9	5.4	1.1	1.4	1.6	0.5	1.8	0.9	1.9
14	8	12.1	13.3	9.0	13.7	15.5	13.4	10.3	6.4	1.3	1.3	1.9	0.5	1.9	0.8	2.3
16	4	6.2	8.5	10.6	5.9	7.1	9.6	6.3	4.1	0.8	1.0	1.5	0.1	1.2	0.3	1.8
16	6	10.1	12.4	9.1	10.6	12.1	10.8	8.6	4.5	1.1	1.3	2.2	0.2	1.5	0.4	2.3
16	8	14.5	16.7	9.7	14.1	14.9	9.6	7.1	4.4	1.3	1.9	3.3	0.3	1.8	0.5	2.1
18	4	8.5	9.8	10.7	6.7	6.8	9.8	8.2	4.1	0.7	1.7	1.9	0.6	2.4	0.4	2.7
18	6	12.2	15.5	8.3	11.0	13.1	8.9	7.3	4.7	0.8	1.8	2.3	0.7	2.3	0.6	2.7
18	8	17.8	15.1	8.7	17.6	13.0	7.7	7.0	4.5	1.0	1.9	2.5	0.9	1.8	0.8	2.3
+2.3 ft swl; 160-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.2	6.6	7.1	7.3	7.2	7.7	5.3	3.4	1.1	1.1	1.4	1.4	1.3	0.9	1.8
11	8	8.7	9.0	8.3	9.5	9.0	8.7	6.5	4.2	1.3	1.3	2.0	1.8	1.7	1.1	2.1
14	4	6.2	6.1	7.7	6.9	7.2	10.4	5.9	4.1	1.2	1.1	2.4	0.5	1.6	0.9	1.7
14	6	8.3	10.4	11.5	7.8	9.7	10.7	9.2	4.7	0.7	1.9	2.9	0.4	1.8	0.4	2.6
14	8	11.8	12.1	11.2	13.0	15.0	14.3	12.1	6.3	1.2	1.3	3.3	0.8	2.5	0.8	2.9
16	4	5.9	7.6	10.4	6.9	7.8	8.5	6.3	3.9	0.6	1.5	2.0	0.2	1.3	0.2	1.9
16	6	9.4	11.6	10.2	11.3	13.8	13.5	10.0	4.5	0.8	2.1	3.3	0.4	1.9	0.4	2.9
16	8	14.9	17.2	10.6	14.4	16.0	10.9	7.7	4.6	0.9	2.5	3.6	0.5	2.4	0.5	2.6
18	4	8.4	8.9	11.8	7.2	7.0	10.0	8.7	4.6	0.7	2.3	2.7	1.3	2.2	0.4	2.2
18	6	9.0	9.5	11.7	7.3	7.5	10.6	9.7	4.7	0.8	2.3	2.8	1.3	2.2	0.4	2.4
18	8	16.2	16.3	8.7	17.5	14.5	8.1	7.3	4.5	1.2	1.8	2.5	1.7	1.8	0.5	2.5

(Sheet 1 of 3)

Table 8 (Continued)

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 180-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	6.7	7.5	7.3	6.3	6.3	7.2	5.3	2.9	0.7	0.7	1.1	1.5	0.8	0.7	1.2
11	8	8.4	9.3	7.4	8.0	8.3	8.1	6.1	3.4	0.8	0.9	1.2	2.4	1.0	0.9	1.4
14	4	4.9	5.6	8.1	4.3	4.6	7.1	7.0	3.2	0.6	0.9	0.8	0.2	1.1	0.3	1.1
14	6	7.7	9.1	10.9	7.7	8.5	10.4	7.9	4.1	0.7	0.9	1.1	0.4	1.3	0.6	1.3
14	8	11.2	12.8	11.2	10.7	11.3	9.8	6.5	4.0	0.7	0.9	1.3	0.4	1.3	0.8	1.4
16	4	4.5	5.2	6.5	4.9	5.8	7.4	5.7	3.3	0.6	0.9	1.9	0.1	1.1	0.5	1.1
16	6	7.6	9.3	9.5	8.4	10.9	11.7	9.5	4.5	0.9	1.4	2.4	0.2	1.5	0.5	1.7
16	8	12.2	14.4	7.6	12.3	13.5	11.8	9.8	5.4	1.0	1.8	2.7	0.4	1.7	0.8	1.9
18	4	5.1	6.3	7.9	6.3	6.5	8.1	4.5	2.7	0.4	1.1	1.3	0.5	1.4	0.5	1.3
18	6	7.2	9.0	12.0	9.7	10.4	12.0	8.6	3.9	0.7	1.5	1.9	0.8	1.8	0.7	2.0
18	8	12.8	14.6	12.7	14.9	15.4	11.6	6.8	4.3	0.7	1.5	2.0	1.0	1.8	0.9	1.8
+2.3 ft swl; 180-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 13	Gage 14	Gage 15	Gage 16
8	6	7.3	8.0	7.7	6.3	6.3	7.2	5.2	2.9	0.8	0.7	1.3	1.5	0.9	0.8	1.3
11	8	8.8	9.6	8.7	8.4	8.8	9.2	6.6	3.5	1.1	1.0	1.7	1.9	1.2	1.1	1.6
14	4	4.7	5.5	7.4	4.8	6.0	6.7	7.1	3.4	1.0	1.0	1.7	0.4	1.4	0.6	1.3
14	6	7.5	9.2	11.2	8.3	9.2	10.5	8.8	4.6	0.7	0.8	1.5	0.5	1.5	1.3	1.8
14	8	11.0	14.1	12.4	10.2	11.3	11.2	7.8	4.4	0.7	0.8	1.8	0.7	1.8	1.3	1.9
16	4	4.3	4.1	5.3	6.6	7.1	9.0	7.1	3.9	0.8	1.8	2.4	0.3	1.6	0.5	1.8
16	6	7.4	7.2	10.7	9.4	10.4	12.5	8.7	4.2	0.6	2.2	2.9	0.4	2.2	0.4	1.9
16	8	11.6	12.8	8.3	14.1	15.4	12.0	10.2	5.3	0.9	2.4	3.6	0.4	2.0	0.8	2.3
18	4	5.2	5.7	7.5	6.3	6.6	7.8	4.7	2.8	0.4	1.4	1.7	1.2	1.2	0.7	1.2
18	6	7.9	8.6	12.7	9.2	10.1	11.7	8.7	4.3	0.6	1.6	2.2	1.5	1.4	1.1	1.5
18	8	13.1	15.6	14.1	14.7	14.4	14.6	7.4	4.6	0.7	1.4	2.0	1.4	1.3	1.3	1.3

(Sheet 2 of 3)

Table 8 (Concluded)

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 215-deg azimuth																
Period sec	**Height ft**	**Gage 1**	**Gage 2**	**Gage 3**	**Gage 4**	**Gage 5**	**Gage 6**	**Gage 7**	**Gage 8**	**Gage 9**	**Gage 10**	**Gage 11**	**Gage 13**	**Gage 14**	**Gage 15**	**Gage 16**
8	6	4.9	5.3	5.8	5.2	5.5	6.3	4.0	1.6	0.6	0.5	0.9	1.6	0.6	0.6	0.8
11	8	6.4	7.1	6.8	7.2	7.6	7.5	4.7	1.9	0.7	0.7	1.1	2.1	0.7	0.7	0.9
14	4	3.9	4.6	6.0	4.4	4.5	5.2	3.9	1.7	0.3	0.4	0.4	0.1	0.3	0.9	0.8
14	6	5.9	7.7	9.5	7.9	7.7	8.5	6.4	2.1	0.4	0.7	0.8	0.3	0.5	0.8	0.8
14	8	8.9	11.1	10.0	11.5	10.2	9.4	6.1	2.5	0.6	0.9	1.3	0.4	0.8	0.8	0.8
16	4	3.0	3.4	5.0	4.5	4.7	4.6	5.0	2.6	0.3	0.5	1.3	0.1	0.7	0.7	0.8
16	6	4.9	5.9	9.7	7.2	7.1	8.7	7.8	3.3	0.5	0.7	1.4	0.2	0.8	0.8	1.2
16	8	8.0	9.6	8.3	9.0	10.1	12.4	7.1	3.5	0.6	0.9	1.5	0.3	0.9	0.7	1.2
18	4	5.8	6.6	7.8	4.8	5.5	8.1	4.4	1.9	0.5	0.7	1.1	0.3	0.9	0.6	0.8
18	6	8.0	9.2	10.5	7.8	9.3	11.6	6.1	2.7	0.5	1.3	1.7	0.6	1.4	0.5	1.1
18	8	11.4	13.9	10.7	12.6	13.7	9.8	5.8	2.7	0.4	1.5	2.1	0.7	1.8	0.6	1.5
+2.3 ft swl; 215-deg azimuth																
Period sec	**Height ft**	**Gage 1**	**Gage 2**	**Gage 3**	**Gage 4**	**Gage 5**	**Gage 6**	**Gage 7**	**Gage 8**	**Gage 9**	**Gage 10**	**Gage 11**	**Gage 13**	**Gage 14**	**Gage 15**	**Gage 16**
8	6	5.2	5.4	6.0	5.4	5.7	6.8	4.1	1.8	0.7	0.6	1.0	1.5	0.7	0.8	0.8
11	8	6.8	7.2	7.3	7.4	7.8	8.2	4.9	2.1	0.8	0.7	1.1	1.9	0.9	0.8	1.0
14	4	3.8	4.4	5.1	4.7	4.2	4.4	3.7	1.7	0.6	0.5	1.1	0.2	0.3	1.0	0.7
14	6	4.8	6.0	8.2	6.3	6.3	8.0	6.7	2.7	0.6	0.5	1.1	0.3	0.5	1.1	1.0
14	8	7.7	10.1	12.1	10.2	9.4	10.3	6.8	2.8	0.5	0.6	1.3	0.5	0.7	1.1	1.1
16	4	3.2	3.6	4.7	4.4	4.1	4.9	4.6	2.6	0.5	1.1	1.3	0.2	0.7	0.5	0.8
16	6	4.8	6.3	8.4	6.8	6.0	9.2	8.4	3.7	0.7	1.1	1.2	0.3	1.0	0.6	1.1
16	8	8.1	9.8	9.9	8.2	9.6	13.6	8.0	4.0	0.7	1.1	1.0	0.4	1.0	0.6	1.2
18	4	5.7	5.4	6.6	4.1	5.4	8.8	3.9	1.9	0.4	0.8	1.0	0.8	0.7	0.7	0.6
18	6	8.3	8.3	9.5	7.9	10.2	13.0	6.0	2.7	0.4	1.3	1.5	1.3	1.1	0.6	0.9
18	8	11.3	12.6	13.5	13.3	15.1	13.3	6.3	3.2	0.4	1.6	1.9	1.5	1.7	0.5	1.1

(Sheet 3 of 3)

Table 9. Wave Heights for Alternative 8

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 160-deg azimuth																
Period Sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	6.0	6.5	6.7	7.0	7.5	7.6	5.0	4.3	1.0	1.2	2.0	1.5	1.7	3.1	1.4
11	8	7.9	8.6	7.5	9.3	9.6	8.2	6.5	5.2	1.3	1.4	2.6	1.7	2.0	3.8	1.8
14	4	5.9	6.5	8.0	6.8	7.9	9.6	8.0	7.1	0.2	0.4	0.8	0.6	0.6	5.2	0.7
14	6	8.3	10.4	12.0	10.8	12.7	12.0	11.1	8.3	0.4	0.7	1.4	0.8	1.1	6.0	1.0
14	8	12.3	13.9	9.8	13.4	15.0	12.1	11.8	9.4	0.5	0.9	2.0	0.8	1.3	6.5	1.4
16	4	6.8	8.5	10.5	6.1	7.9	9.1	8.2	7.2	1.5	1.2	1.4	2.5	2.1	4.2	1.2
16	6	9.1	11.7	8.9	9.3	11.6	8.7	8.5	7.7	1.5	1.1	1.4	2.3	2.0	4.8	1.0
16	8	13.0	16.1	9.5	14.6	15.6	8.4	9.1	8.3	1.2	1.0	1.6	1.7	2.2	5.7	1.3
18	4	6.7	8.7	10.6	7.1	8.3	10.5	7.8	6.2	0.4	0.3	1.6	1.0	1.0	3.9	1.4
18	6	11.0	14.7	8.7	11.0	13.0	8.0	8.0	6.8	0.4	0.4	1.9	1.1	0.7	4.0	1.1
18	8	16.3	15.5	8.6	15.4	16.8	6.9	7.5	6.0	0.5	0.5	2.1	1.1	0.7	4.5	1.5
+2.3 ft swl; 160-deg azimuth																
Period Sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	6.1	6.6	7.4	7.1	7.2	8.0	5.3	4.5	1.1	1.3	2.6	1.6	1.9	3.4	1.8
11	8	8.2	8.8	8.2	9.2	9.2	8.9	6.9	5.8	1.4	1.5	3.0	1.9	2.1	4.2	2.0
14	4	5.2	5.2	6.1	7.1	7.1	11.3	7.2	6.2	0.5	0.5	2.2	0.5	0.5	4.9	0.6
14	6	8.0	8.3	11.4	10.0	10.8	14.3	10.0	8.9	0.7	1.3	2.7	0.8	1.5	6.6	1.3
14	8	11.1	12.5	11.9	12.7	14.1	14.8	11.2	9.3	0.6	1.3	2.3	1.0	1.4	6.9	1.7
16	4	6.3	8.2	11.8	7.2	8.4	9.3	7.3	7.8	1.2	0.7	1.1	1.2	2.3	5.1	1.6
16	6	9.6	11.5	12.5	9.2	11.1	10.8	9.6	10.6	1.4	1.0	1.4	1.2	2.6	6.2	1.9
16	8	13.3	16.3	11.5	15.0	14.9	10.1	10.6	10.4	1.6	0.8	1.1	0.9	2.0	6.1	1.9
18	4	8.6	8.8	12.0	7.0	8.6	9.6	8.2	8.6	0.5	0.6	1.1	0.9	0.5	4.3	1.4
18	6	9.8	11.9	10.3	12.2	13.9	11.1	8.3	8.6	0.7	0.7	1.5	1.1	0.9	4.9	1.2
18	8	16.8	16.1	9.2	16.7	16.3	7.8	7.8	7.6	0.5	1.0	2.7	1.1	1.1	6.2	2.3

(Sheet 1 of 3)

Table 9 (Continued)

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 180-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	6.5	7.2	6.9	6.1	6.3	6.8	5.0	4.1	0.8	1.1	2.1	1.4	1.5	2.8	1.4
11	8	8.4	9.4	7.5	8.3	8.4	7.6	6.4	5.0	1.0	1.3	2.7	1.6	1.7	3.5	1.7
14	4	4.9	5.5	7.5	5.3	5.7	7.7	5.1	5.2	0.2	0.3	0.7	0.4	0.3	2.9	0.4
14	6	8.3	9.9	11.0	7.8	8.4	9.6	8.0	7.6	0.3	0.5	1.8	0.5	0.5	4.5	1.3
14	8	11.4	13.7	10.5	11.0	11.1	8.3	8.0	6.5	0.5	0.8	1.8	0.8	0.7	4.6	1.9
16	4	4.1	4.9	6.5	4.9	5.2	7.4	2.9	2.7	0.7	0.8	1.4	1.1	0.9	1.8	1.3
16	6	7.9	10.0	9.1	6.6	7.7	9.4	8.0	7.0	1.1	0.8	1.4	1.6	1.4	4.0	2.1
16	8	11.3	13.4	8.1	10.0	10.7	11.7	11.3	8.0	1.1	1.0	2.0	1.5	1.7	4.9	2.7
18	4	5.0	6.2	8.0	5.7	6.5	7.9	4.4	3.8	0.4	0.3	0.9	0.5	0.9	2.6	1.6
18	6	8.1	10.2	12.4	8.6	10.1	10.6	6.7	6.7	0.4	0.4	1.7	0.7	0.9	3.9	2.2
18	8	12.3	14.3	10.0	14.5	14.0	8.9	8.1	6.7	0.7	0.6	2.5	1.0	0.9	4.8	3.0
+2.3 ft swl; 180-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	6.6	7.5	7.5	6.3	6.3	7.0	5.3	4.3	1.0	1.2	2.3	1.4	1.7	3.1	1.7
11	8	9.6	10.0	8.0	8.6	8.6	8.4	6.9	5.4	1.2	1.5	2.8	1.7	1.9	3.9	2.1
14	4	4.8	5.7	7.4	5.2	4.9	5.5	4.8	4.1	0.3	0.4	1.2	0.3	0.3	2.9	0.6
14	6	8.0	9.6	10.7	7.9	8.5	9.7	7.6	6.7	0.4	0.7	1.6	0.5	0.6	4.7	1.7
14	8	10.8	12.5	12.2	10.9	11.3	9.8	9.3	6.9	0.7	0.7	1.6	0.8	0.8	5.2	2.5
16	4	4.1	4.5	6.0	5.2	5.7	7.0	4.2	3.7	0.7	0.6	0.9	0.9	1.5	3.2	1.6
16	6	7.0	8.2	10.5	7.7	8.9	11.2	9.7	8.6	1.0	0.8	1.2	0.7	2.1	5.5	3.0
16	8	9.7	12.1	9.5	10.4	11.3	12.3	12.7	9.8	1.3	0.9	1.3	0.7	2.2	6.2	4.0
18	4	5.1	5.2	7.0	5.5	5.5	7.3	4.4	4.3	0.5	0.8	1.4	1.2	0.5	3.4	2.6
18	6	8.1	9.8	11.7	8.9	9.4	12.0	7.4	6.4	0.7	0.7	2.1	1.2	0.8	6.2	3.9
18	8	12.8	15.0	12.1	13.6	13.8	12.7	9.1	6.7	0.6	0.8	2.7	1.1	1.1	5.5	4.5

(Sheet 2 of 3)

Table 9 (Concluded)

Experimental Waves		Wave Height, ft, at Indicated Gage Location														
+1.0 ft swl; 215-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	5.0	5.6	6.2	5.5	5.6	6.4	4.7	4.3	0.8	1.1	1.4	1.4	1.4	2.9	1.5
11	8	6.7	7.4	6.8	7.4	7.5	7.7	6.0	5.0	1.0	1.3	1.6	1.5	1.6	3.6	1.9
14	4	4.1	4.8	5.3	4.0	3.8	5.0	5.2	5.3	0.2	0.5	0.6	0.6	0.8	3.6	1.6
14	6	7.0	7.6	9.5	5.9	6.5	7.8	9.9	8.3	0.3	0.6	0.9	0.9	1.0	5.1	2.0
14	8	9.2	11.9	9.5	10.3	9.6	8.5	10.2	8.4	0.4	0.8	1.0	0.8	1.1	6.2	2.2
16	4	3.8	4.5	7.4	5.1	5.5	6.1	5.4	4.0	0.9	0.8	0.9	1.3	1.0	2.3	2.0
16	6	7.3	9.0	9.5	6.8	6.6	10.3	5.5	7.0	1.1	0.8	0.9	1.6	1.3	4.0	2.4
16	8	8.9	10.1	9.1	9.8	10.3	12.7	7.4	5.6	1.2	0.7	1.0	1.8	1.5	4.0	3.2
18	4	6.0	7.3	9.2	4.7	4.8	7.0	6.0	4.1	0.4	0.3	0.5	0.5	0.9	2.7	1.6
18	6	9.6	11.8	11.4	7.9	8.7	10.7	8.8	5.4	0.4	0.4	0.6	0.6	0.7	3.4	2.1
18	8	13.2	16.2	9.1	12.4	12.2	9.4	9.1	5.8	0.7	0.5	1.0	0.9	0.9	4.2	2.0
+2.3 ft swl; 215-deg azimuth																
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
8	6	5.3	5.8	6.6	5.7	5.9	7.0	4.7	4.6	1.0	1.2	2.1	1.5	1.6	3.2	2.2
11	8	6.8	7.6	7.6	7.4	7.7	8.2	6.2	5.6	1.2	1.4	2.4	1.6	1.8	4.0	2.5
14	4	4.2	4.7	5.3	4.7	4.5	5.5	5.3	4.3	0.4	0.3	1.1	0.4	0.3	3.0	2.4
14	6	6.6	7.9	9.3	6.8	7.7	9.0	9.5	8.0	0.4	0.5	1.4	0.4	0.5	5.8	3.1
14	8	8.5	10.9	11.3	10.0	9.4	9.5	11.2	8.2	0.6	0.9	1.8	0.7	1.1	6.3	3.4
16	4	4.0	5.0	7.7	5.2	5.8	6.1	6.1	4.6	0.7	0.7	1.0	1.0	1.7	3.7	3.2
16	6	5.5	6.9	10.2	6.3	6.5	11.5	5.7	7.4	0.8	0.6	1.0	0.9	1.8	4.2	3.6
16	8	9.1	10.2	9.6	10.0	10.1	12.3	9.3	7.3	1.1	0.8	1.1	1.0	2.1	5.1	4.6
18	4	6.6	6.8	8.7	5.2	5.3	7.3	6.8	4.3	0.3	0.5	0.7	0.9	0.4	3.3	2.4
18	6	9.5	11.6	12.9	7.4	9.3	11.3	8.4	6.7	0.4	0.6	0.9	1.0	0.5	3.5	2.9
18	8	13.2	15.8	12.5	12.7	12.1	11.7	9.6	7.1	0.6	0.6	1.4	1.1	0.7	4.8	3.0

(Sheet 3 of 3)

Table 10 Maximum Current Velocities Observed for Alternative 8, +1.0 ft swl					
Experimental Wave Condition		**Maximum Current Velocity, fps**			
Period, sec	**Height, ft**	**Gage 1**	**Gage 2**	**Gage 3**	**Gage 4**
8	6	6.3	3.6	3.4	3.0
11	8	6.7	3.9	3.8	3.9
14	4	2.6	1.8	1.1	1.0
14	6	4.0	2.0	1.8	1.8
14	8	5.1	2.6	2.7	2.8
16	4	3.8	1.9	2.4	1.9
16	6	5.5	2.4	2.8	1.9
16	8	6.3	3.6	3.9	2.8
18	4	2.8	1.9	1.4	1.0
18	6	4.6	2.0	1.9	1.5
18	8	6.5	3.1	3.1	2.4

Table 11 Maximum Current Velocities Observed for Alternative 8, +2.3 ft swl					
Experimental Wave Condition		**Maximum Current Velocity, fps**			
Period, sec	**Height, ft**	**Gage 1**	**Gage 2**	**Gage 3**	**Gage 4**
8	6	6.7	3.3	3.7	3.0
11	8	6.7	3.8	3.9	3.3
14	4	2.2	1.5	1.7	1.1
14	6	3.9	2.1	1.8	1.8
14	8	5.3	2.2	2.0	2.2
16	4	3.7	2.4	2.0	1.4
16	6	6.1	2.8	2.3	2.1
16	8	7.3	3.5	3.1	2.4
18	4	3.9	1.8	1.5	1.6
18	6	6.4	2.5	2.0	2.1
18	8	6.4	3.1	3.1	2.3

Table 12
Wave Height Comparisons for Existing Conditions, Alternatives 1, 1a, 2a, 3a, and 8 from 160, 180, and 215 deg, +1.0 ft swl

Maalaea Harbor								
Experiment Waves			**Average Wave Height (ft), at Indicated Location**					
Plan No.	**Period sec**	**Height ft**	**Surf Zone 160 deg**	**Harbor 160 deg**	**Surf Zone 180 deg**	**Harbor 180 deg**	**Surf Zone 215 deg**	**Harbor 215 deg**
Existing Conditions	8	6.0	7.3	2.2	6.9	1.8	7.8	1.7
Alternative 1	8	6.0	6.9	1.6	6.6	1.2	5.4	0.8
Alternative 1a	8	6.0	7.0	1.2	6.7	0.9	*	*
Alternative 2a	8	6.0	*	*	6.9	1.0	5.6	0.7
Alternative 3a	8	6.0	6.9	1.2	6.9	1.0	5.5	0.8
Alternative 8	8	6.0	6.9	1.7	6.6	1.6	5.7	1.5
Existing Conditions	11	8.0	9.0	2.5	8.4	1.9	7.4	2.0
Alternative 1	11	8.0	8.5	2.0	8.1	1.5	7.3	1.0
Alternative 1a	11	8.0	8.8	1.4	8.0	1.1	*	*
Alternative 2a	11	8.0	*	*	8.2	1.2	7.3	0.9
Alternative 3a	11	8.0	8.5	1.4	8.3	1.2	7.1	1.1
Alternative 8	11	8.0	8.5	2.2	8.3	2.0	7.2	1.8
Existing Conditions	14	4.0	5.5	2.2	6.0	1.4	4.3	1.5
Alternative 1	14	4.0	7.7	1.0	5.6	0.8	5.1	0.5
Alternative 1a	14	4.0	7.8	0.8	5.7	0.7	*	*
Alternative 2a	14	4.0	*	*	5.9	0.6	4.5	0.4
Alternative 3a	14	4.0	8.0	0.8	5.8	0.6	4.8	0.4
Alternative 8	14	4.0	7.5	1.4	6.1	0.9	4.5	1.1

* Waves Not Studied

(Sheet 1 of 4)

Table 12 (Continued)								
Maalaea Harbor								
Experiment Waves			**Average Wave Height (ft), at Indicated Location**					
Plan No.	**Period sec**	**Height ft**	**Surf Zone 160 deg**	**Harbor 160 deg**	**Surf Zone 180 deg**	**Harbor 180 deg**	**Surf Zone 215 deg**	**Harbor 215 deg**
Existing Conditions	14	6.0	9.5	2.9	9.6	1.6	7.7	1.7
Alternative 1	14	6.0	10.9	1.3	8.9	1.0	7.8	0.7
Alternative 1a	14	6.0	10.9	1.0	8.6	0.8	*	*
Alternative 2a	14	6.0	*	*	9.3	0.7	7.6	0.4
Alternative 3a	14	6.0	10.7	1.1	9.1	0.7	7.9	0.6
Alternative 8	14	6.0	11.0	1.9	9.2	1.5	7.4	1.6
Existing Conditions	14	8.0	12.4	2.5	11.6	1.8	9.8	2.1
Alternative 1	14	8.0	12.8	1.4	11.2	1.0	10.5	0.9
Alternative 1a	14	8.0	13.2	1.2	10.8	1.0	*	*
Alternative 2a	14	8.0	*	*	11.4	0.8	10.4	0.4
Alternative 3a	14	8.0	12.8	1.2	11.2	0.8	10.2	0.8
Alternative 8	14	8.0	12.7	2.1	11.0	1.7	9.8	1.8
Existing Conditions	16	4.0	6.8	2.3	6.2	2.3	4.6	2.0
Alternative 1	16	4.0	7.8	1.3	5.4	1.0	3.8	1.0
Alternative 1a	16	4.0	8.4	0.8	5.6	0.8	*	*
Alternative 2a	16	4.0	*	*	5.6	0.9	3.9	0.6
Alternative 3a	16	4.0	8.0	0.7	5.7	0.8	4.2	0.6
Alternative 8	16	4.0	8.1	2.2	5.5	1.2	5.4	1.2

(Sheet 2 of 4)

Table 12 (Continued)								
Maalaea Harbor								
Experiment Waves			Average Wave Height (ft), at Indicated Location					
Plan No.	Period Sec	Height Ft	Surf Zone 160 deg	Harbor 160 deg	Surf Zone 180 deg	Harbor 180 deg	Surf Zone 215 deg	Harbor 215 deg
Existing Conditions	16	6.0	10.9	2.9	9.3	2.2	8.3	2.1
Alternative 1	16	6.0	11.1	1.5	9.3	1.4	7.4	1.0
Alternative 1a	16	6.0	11.3	1.0	9.9	1.3	*	*
Alternative 2a	16	6.0	*	*	9.3	1.2	6.9	0.8
Alternative 3a	16	6.0	10.8	1.0	9.6	1.1	7.3	0.7
Alternative 8	16	6.0	9.9	2.2	8.5	1.8	8.2	1.7
Existing Conditions	16	8.0	12.2	2.7	11.7	2.2	10.3	2.1
Alternative 1	16	8.0	13.5	1.7	11.0	1.5	9.7	1.3
Alternative 1a	16	8.0	14.2	1.2	12.1	1.6	*	*
Alternative 2a	16	8.0	*	*	11.9	1.4	9.7	0.8
Alternative 3a	16	8.0	13.2	1.5	12.0	1.3	9.5	0.8
Alternative 8	16	8.0	12.9	2.2	10.8	2.1	10.1	1.7
Existing Conditions	18	4.0	8.3	1.6	6.7	1.2	6.3	1.4
Alternative 1	18	4.0	8.9	1.6	6.2	1.3	6.3	1.1
Alternative 1a	18	4.0	8.5	1.0	6.3	0.9	*	*
Alternative 2a	18	4.0	*	*	6.3	0.7	5.5	0.6
Alternative 3a	18	4.0	8.7	1.1	6.7	0.8	6.4	0.6
Alternative 8	18	4.0	8.6	1.4	6.6	1.0	10.0	0.9
								(Sheet 3 of 4)

Table 12 (Concluded)								
Maalaea Harbor								
Experiment Waves			**Average Wave Height (ft), at Indicated Location**					
Plan No.	**Period sec**	**Height ft**	**Surf Zone 160 deg**	**Harbor 160 deg**	**Surf Zone 180 deg**	**Harbor 180 deg**	**Surf Zone 215 deg**	**Harbor 215 deg**
Existing Conditions	18	6.0	11.2	2.2	10.1	1.4	10.4	1.4
Alternative 1	18	6.0	11.5	1.6	9.3	2.0	9.5	1.4
Alternative 1a	18	6.0	11.5	1.1	9.7	1.2	*	*
Alternative 2a	18	6.0	*	*	9.9	1.0	10.5	0.7
Alternative 3a	18	6.0	11.5	1.2	10.0	1.1	9.4	0.9
Alternative 8	18	6.0	11.1	1.6	10.0	1.4	10.0	1.1
Existing Conditions	18	8.0	13.4	2.1	12.8	1.6	13.2	1.7
Alternative 1	18	8.0	13.0	1.9	12.7	2.2	11.3	1.6
Alternative 1a	18	8.0	13.3	1.1	12.9	1.3	*	*
Alternative 2a	18	8.0	*	*	12.9	1.2	11.9	1.1
Alternative 3a	18	8.0	13.3	1.4	13.6	1.2	12.0	1.1
Alternative 8	18	8.0	13.2	1.8	12.3	1.9	12.1	1.5

(Sheet 4 of 4)

Table 13
Wave Height Comparisons for Existing Conditions, Alternatives 1, 1a, 2a, 3a, and 8 from 160, 180, and 215 deg, +2.3 ft swl

Maalaea Harbor								
Experiment Waves			**Average Wave Height (ft), at Indicated Location**					
Plan No.	**Period sec**	**Height ft**	**Surf Zone 160 deg**	**Harbor 160 deg**	**Surf Zone 180 deg**	**Harbor 180 deg**	**Surf Zone 215 deg**	**Harbor 215 deg**
Existing Conditions	8	6.0	7.5	2.5	7.8	2.2	5.7	1.9
Alternative 1	8	6.0	7.1	1.5	6.7	1.2	5.5	0.8
Alternative 1a	8	6.0	7.2	1.3	6.8	1.0	*	*
Alternative 2a	8	6.0	*	*	*	*	5.9	0.8
Alternative 3a	8	6.0	7.0	1.2	7.1	1.0	5.8	0.9
Alternative 8	8	6.0	7.1	2.0	6.9	1.8	6.1	1.8
Existing Conditions	11	8.0	9.3	2.7	9.0	2.4	7.4	2.1
Alternative 1	11	8.0	8.9	1.8	8.6	1.6	7.4	1.1
Alternative 1a	11	8.0	8.9	1.6	8.5	1.3	*	*
Alternative 2a	11	8.0	*	*	*	*	7.4	1.0
Alternative 3a	11	8.0	8.9	1.5	8.9	1.3	7.4	1.1
Alternative 8	11	8.0	8.8	2.4	8.9	2.2	7.6	2.1
Existing Conditions	14	4.0	5.8	2.4	5.8	1.3	4.6	2.0
Alternative 1	14	4.0	7.1	1.3	5.5	1.4	4.7	0.8
Alternative 1a	14	4.0	7.2	1.1	5.4	1.2	*	*
Alternative 2a	14	4.0	*	*	*	*	4.5	0.3
Alternative 3a	14	4.0	7.4	1.2	5.9	0.9	4.4	0.7
Alternative 8	14	4.0	7.0	1.7	5.6	1.0	4.8	1.0

* Waves Not Studied

(Sheet 1 of 4)

Table 13 (Continued)									
Maalaea Harbor									
Experiment Waves			**Average Wave Height (ft), at Indicated Location**						
Plan No.	**Period sec**	**Height ft**	**Surf Zone 160 deg**	**Harbor 160 deg**	**Surf Zone 180 deg**	**Harbor 180 deg**	**Surf Zone 215 deg**	**Harbor 215 deg**
Existing Conditions	14	6.0	9.6	3.4	9.1	2.3	7.1	2.1
Alternative 1	14	6.0	10.4	1.9	8.5	1.4	6.6	1.0
Alternative 1a	14	6.0	10.4	1.4	8.5	1.0	*	*
Alternative 2a	14	6.0	*	*	*	*	7.4	0.6
Alternative 3a	14	6.0	10.5	1.3	9.3	1.0	6.6	0.7
Alternative 8	14	6.0	10.4	2.4	9.1	1.6	7.9	1.7
Existing Conditions	14	8.0	12.7	3.2	11.7	2.5	9.5	2.4
Alternative 1	14	8.0	12.6	1.9	11.5	1.3	6.6	1.2
Alternative 1a	14	8.0	12.8	1.5	11.7	1.0	*	*
Alternative 2a	14	8.0	*	*	*	*	10.7	0.8
Alternative 3a	14	8.0	12.9	1.5	11.7	1.1	10.0	0.8
Alternative 8	14	8.0	12.9	2.4	11.2	1.8	9.9	2.1
Existing Conditions	16	4.0	6.8	1.9	5.7	2.4	4.3	1.7
Alternative 1	16	4.0	7.9	1.4	5.4	1.3	4.3	1.1
Alternative 1a	16	4.0	7.8	1.2	6.0	1.3	*	*
Alternative 2a	16	4.0	*	*	*	*	4.3	1.0
Alternative 3a	16	4.0	7.8	0.9	6.1	1.2	4.2	0.7
Alternative 8	16	4.0	8.5	1.9	5.4	1.3	5.6	1.4

(Sheet 2 of 4)

Table 13 (Continued)								
Maalaea Harbor								
Experiment Waves			**Average Wave Height (ft), at Indicated Location**					
Plan No.	**Period sec**	**Height ft**	**Surf Zone 160 deg**	**Harbor 160 deg**	**Surf Zone 180 deg**	**Harbor 180 deg**	**Surf Zone 215 deg**	**Harbor 215 deg**
Existing Conditions	16	6.0	10.7	2.9	9.6	2.6	8.0	1.8
Alternative 1	16	6.0	11.9	1.6	8.8	1.7	7.1	1.3
Alternative 1a	16	6.0	12.1	1.4	9.6	1.6	*	*
Alternative 2a	16	6.0	*	*	*	*	7.3	1.1
Alternative 3a	16	6.0	11.6	1.4	9.6	1.3	6.9	0.8
Alternative 8	16	6.0	10.8	2.2	8.9	1.8	7.8	1.5
Existing Conditions	16	8.0	13.1	2.9	11.6	2.7	10.1	1.9
Alternative 1	16	8.0	14.2	1.7	11.4	1.9	9.8	1.3
Alternative 1a	16	8.0	14.5	1.5	12.3	1.8	*	*
Alternative 2a	16	8.0	*	*	*	*	10.2	1.1
Alternative 3a	16	8.0	14.0	1.6	12.4	1.6	9.9	0.8
Alternative 8	16	8.0	13.5	2.1	10.9	2.1	10.2	1.8
Existing Conditions	18	4.0	8.1	2.2	6.3	1.3	5.7	1.7
Alternative 1	18	4.0	8.4	1.8	6.1	1.5	6.4	1.4
Alternative 1a	18	4.0	8.6	1.6	6.6	1.2	*	*
Alternative 2a	18	4.0	*	*	*	*	6.6	1.0
Alternative 3a	18	4.0	8.9	1.5	6.5	1.1	6.0	0.7
Alternative 8	18	4.0	9.1	1.5	5.9	1.4	6.7	1.1

(Sheet 3 of 4)

Table 13 (Concluded)									
Maalaea Harbor									
Experiment Waves			Average Wave Height (ft), at Indicated Location						
Plan No.	Period sec	Height ft	Surf Zone 160 deg	Harbor 160 deg	Surf Zone 180 deg	Harbor 180 deg	Surf Zone 215 deg	Harbor 215 deg
Existing Conditions	18	6.0	11.0	2.5	10.6	1.8	9.7	1.9
Alternative 1	18	6.0	11.3	1.7	9.9	2.2	10.3	1.4
Alternative 1a	18	6.0	11.8	1.5	10.5	1.5	*	*
Alternative 2a	18	6.0	*	*	*	*	9.8	1.1
Alternative 3a	18	6.0	11.7	1.5	10.0	1.4	9.5	1.0
Alternative 8	18	6.0	11.5	1.8	10.0	2.2	10.3	1.3
Existing Conditions	18	8.0	13.5	2.5	13.4	1.9	13.2	2.0
Alternative 1	18	8.0	13.3	1.8	14.4	2.3	11.9	1.6
Alternative 1a	18	8.0	13.2	1.5	14.4	1.6	*	*
Alternative 2a	18	8.0	*	*	*	*	13.9	1.2
Alternative 3a	18	8.0	13.5	1.5	14.4	1.3	13.2	1.2
Alternative 8	18	8.0	13.8	2.3	13.3	2.1	13.0	1.7

(Sheet 4 of 4)

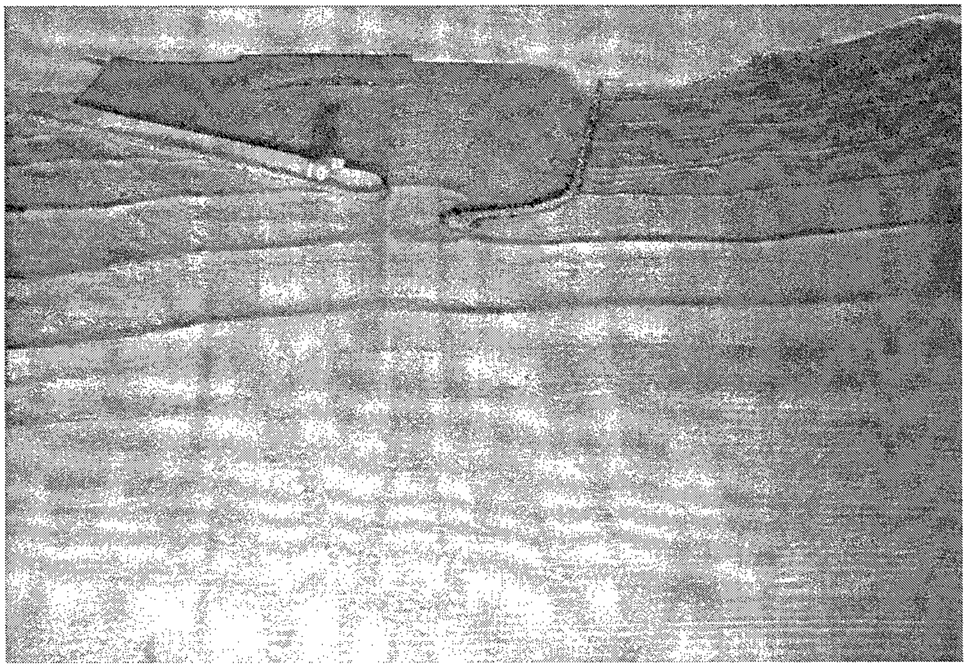


Photo 1. Typical wave patterns for existing conditions; 8-sec, 3-ft waves from 160 deg; swl = +1.0 ft mllw

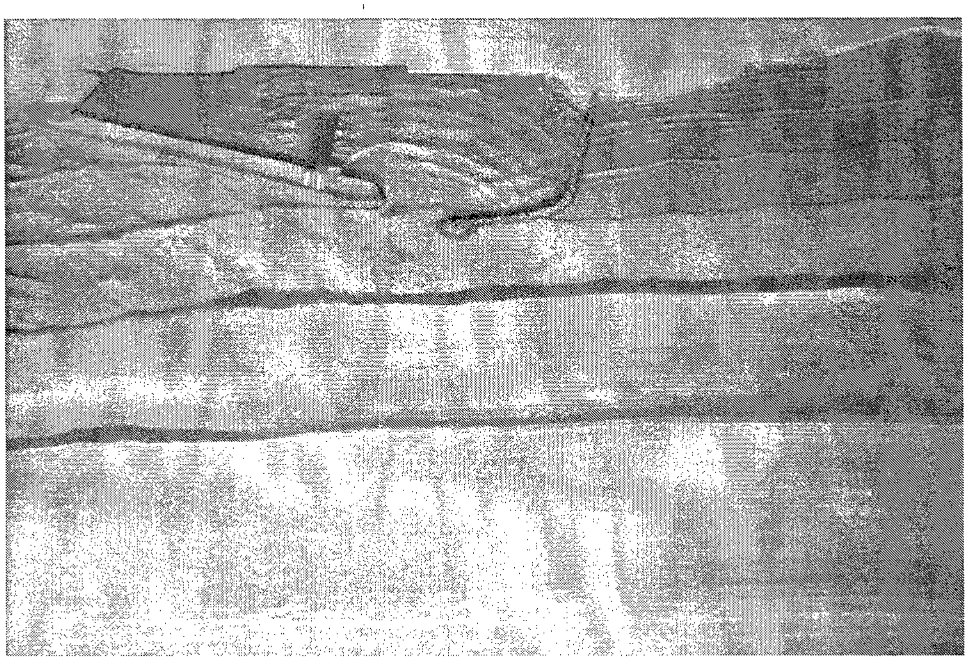


Photo 2. Typical wave patterns for existing conditions; 14-sec, 6-ft waves from 160 deg; swl = +1.0 ft mllw

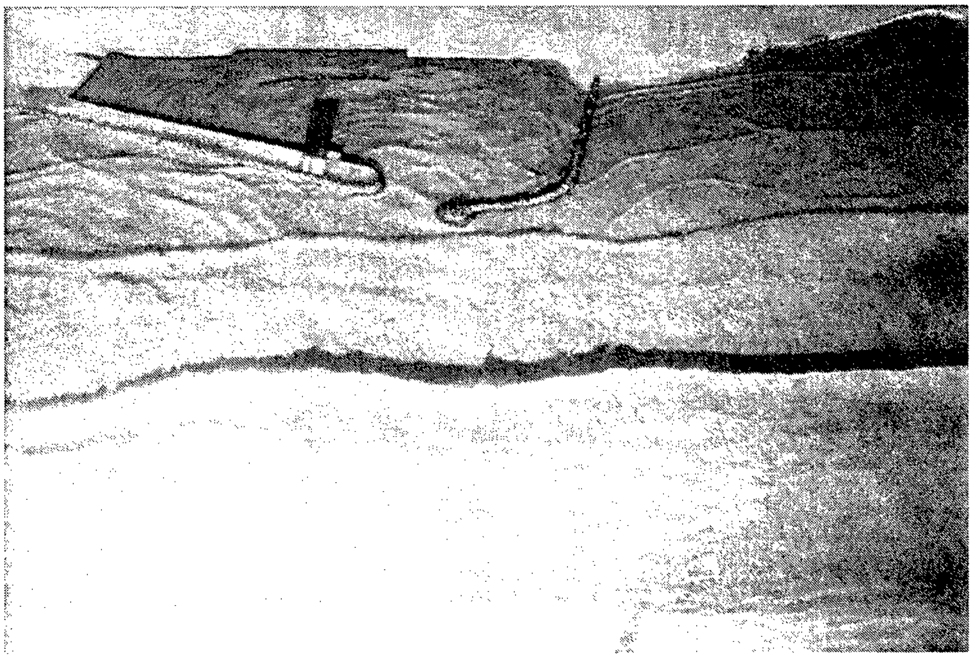


Photo 3. Typical wave patterns for existing conditions; 18-sec, 8-ft waves from 160 deg; swl = +1.0 ft mllw

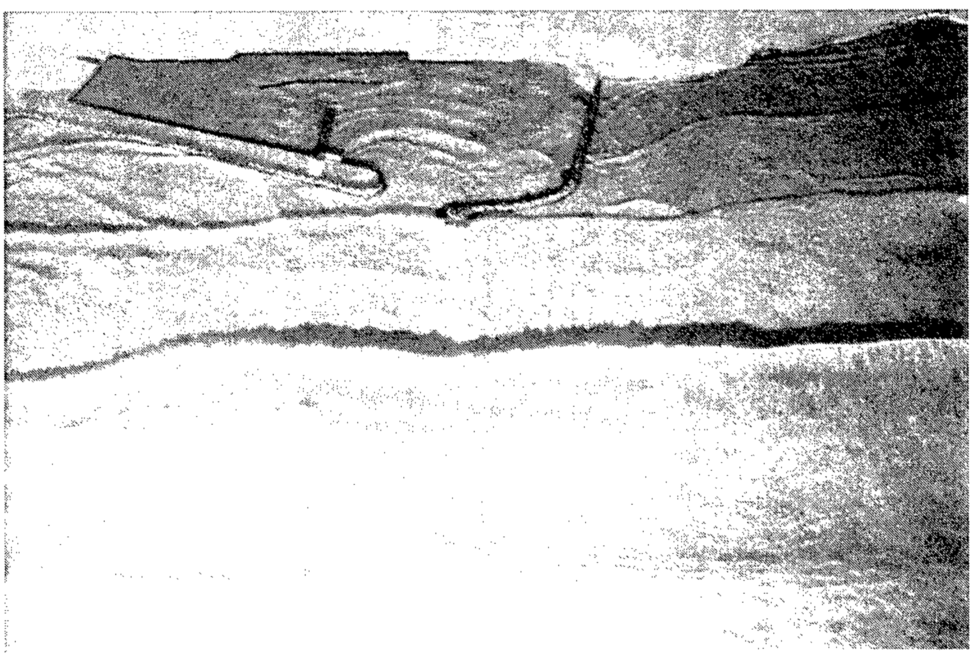


Photo 4. Typical wave patterns for existing conditions; 18-sec, 8-ft waves from 160 deg; swl = +2.3 ft mllw

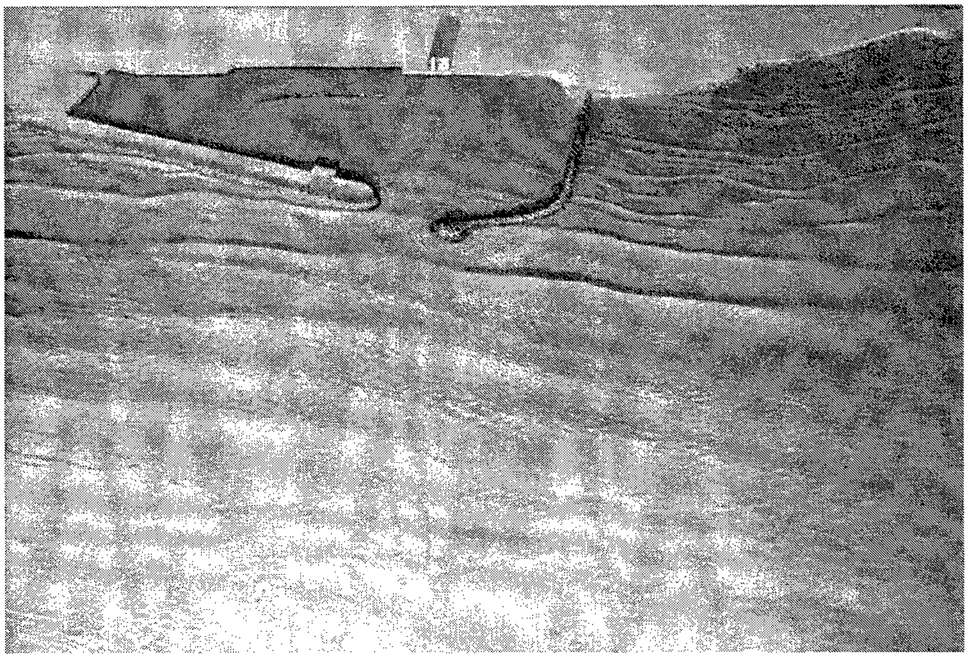


Photo 5. Typical wave patterns for existing conditions; 8-sec, 3-ft waves from 180 deg; swl = +1.0 ft mllw

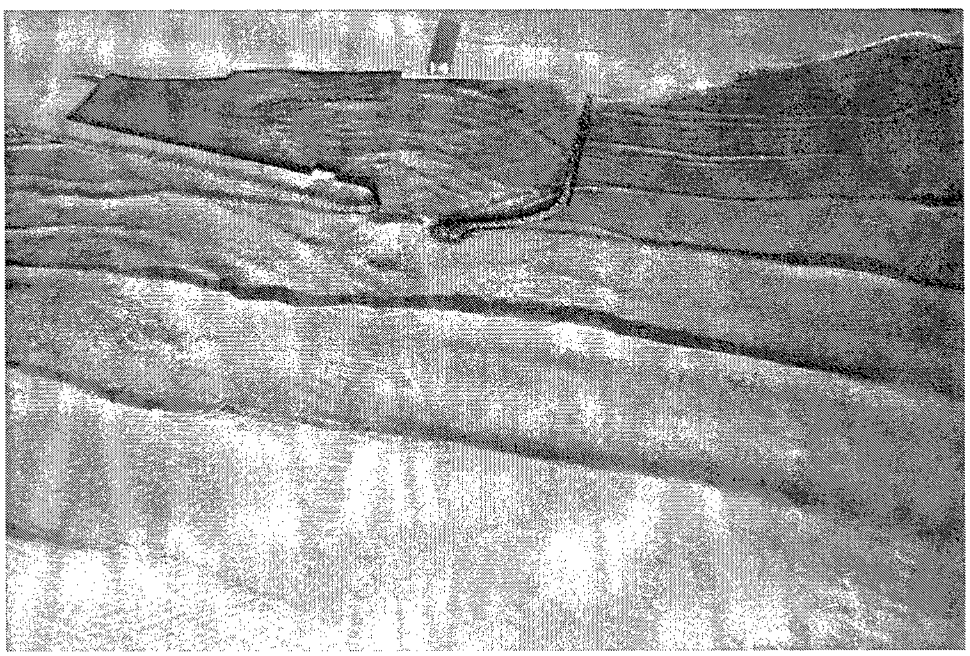


Photo 6. Typical wave patterns for existing conditions; 14-sec, 6-ft waves from 180 deg; swl = +1.0 ft mllw

Photo 7. Typical wave patterns for existing conditions; 18-sec, 8-ft waves from 180 deg; swl = +1.0 ft mllw

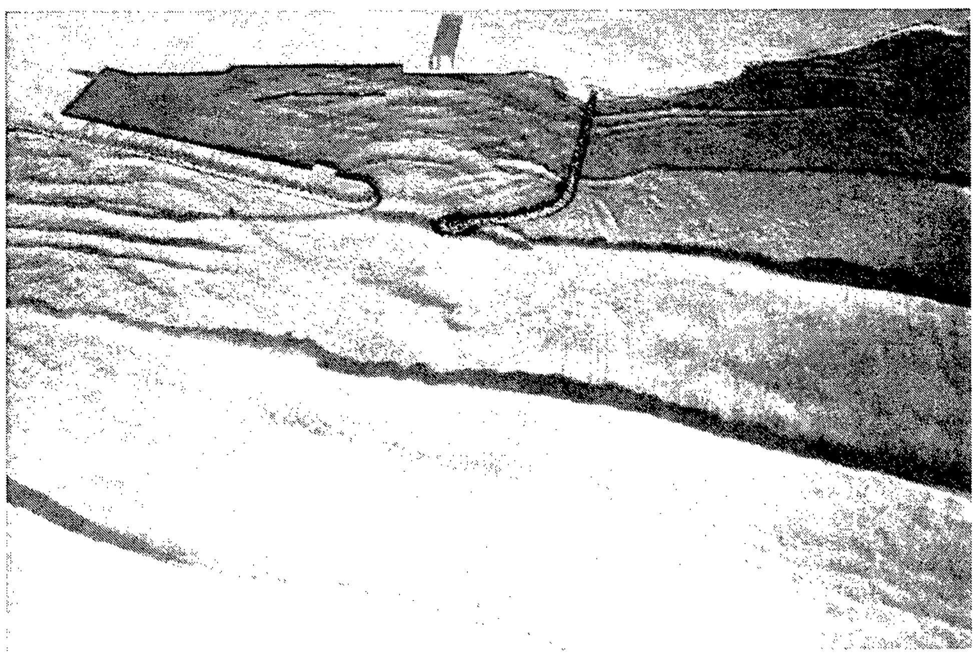


Photo 8. Typical wave patterns for existing conditions; 18-sec, 8-ft waves from 180 deg; swl = +2.3 ft mllw

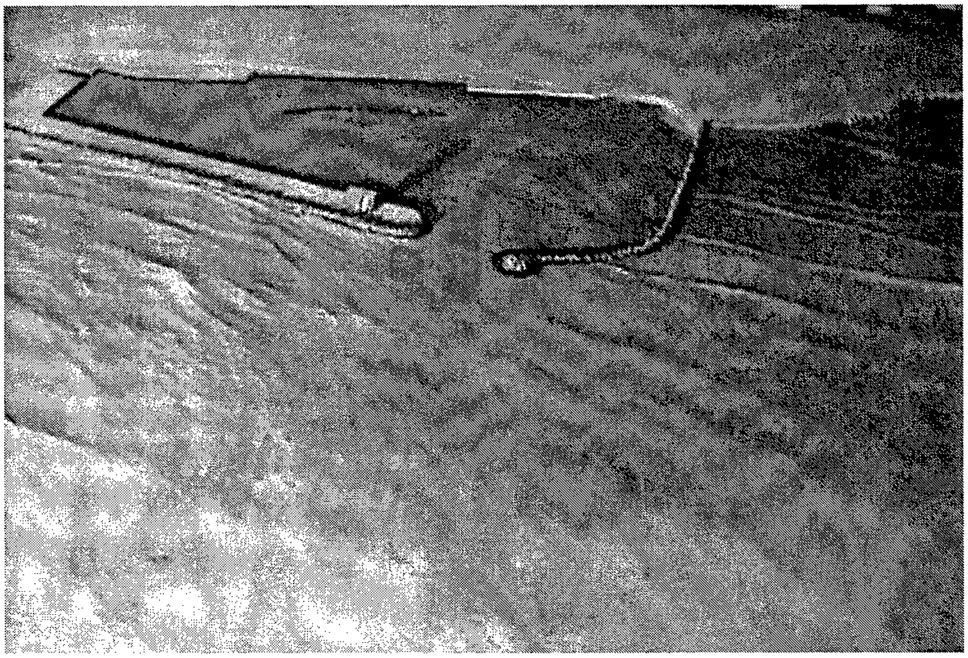


Photo 9. Typical wave patterns for existing conditions; 8-sec, 3-ft waves from 215 deg; swl = +1.0 ft mllw

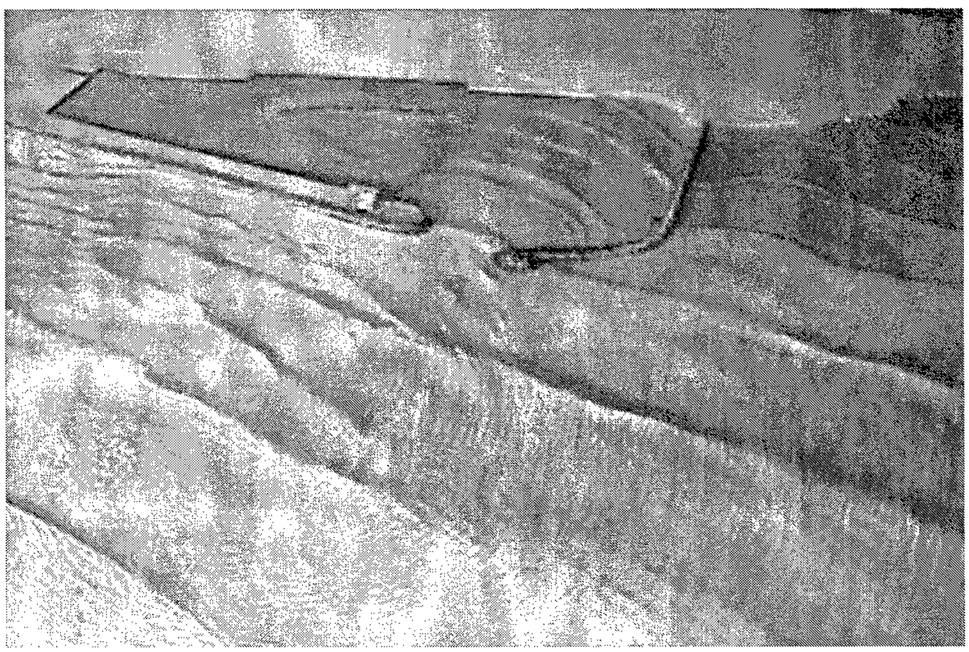


Photo 10. Typical wave patterns for existing conditions; 14-sec, 6-ft waves from 215 deg; swl = +1.0 ft mllw

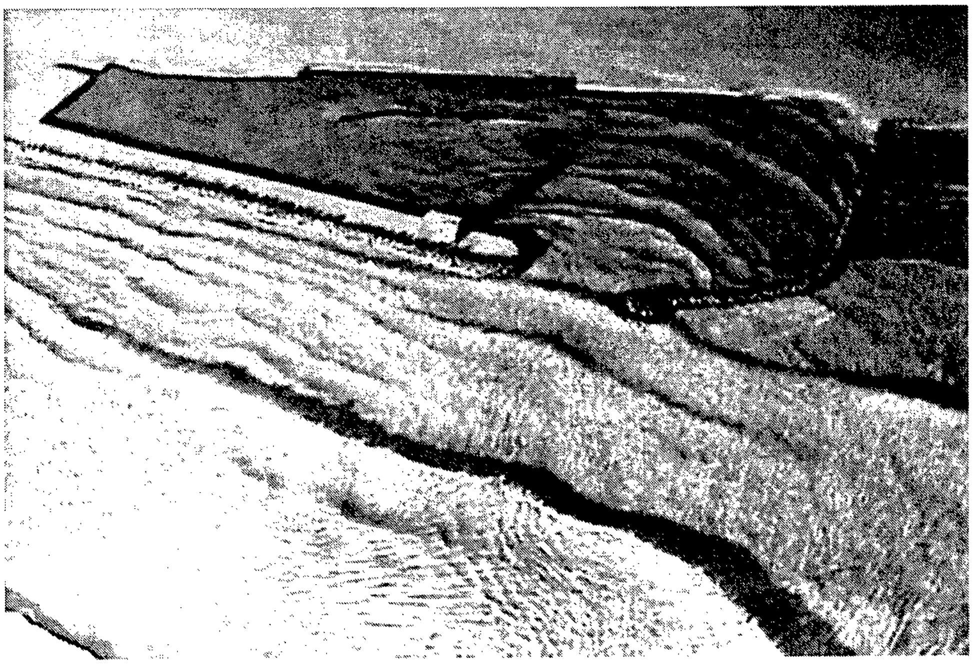


Photo 11. Typical wave patterns for existing conditions; 18-sec, 8-ft waves from 215 deg; swl = +1.0 ft mllw

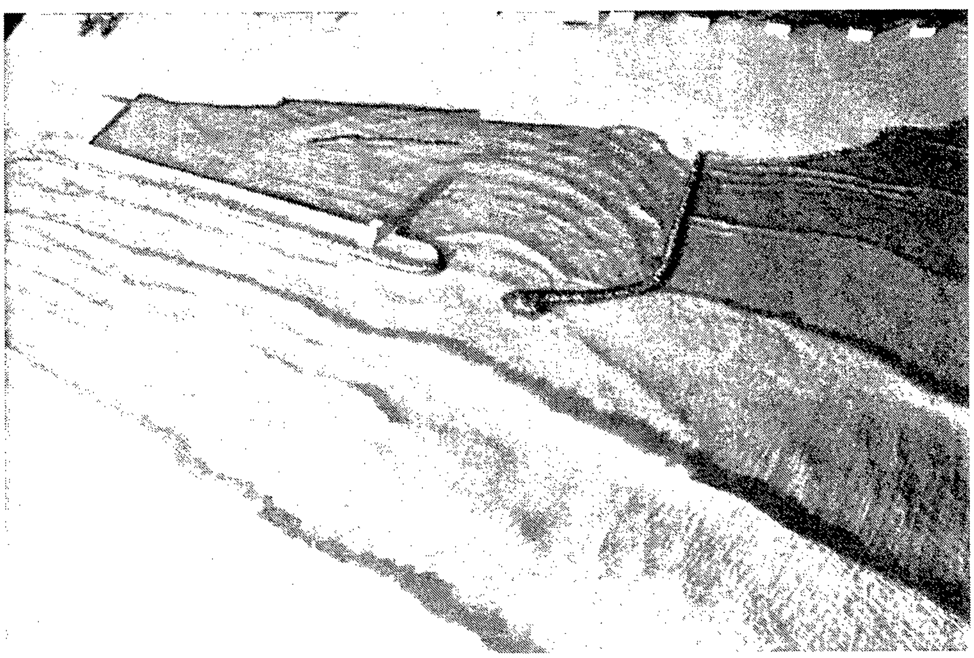


Photo 12. Typical wave patterns for existing conditions; 18-sec, 8-ft waves from 215 deg; swl = +2.3 ft mllw

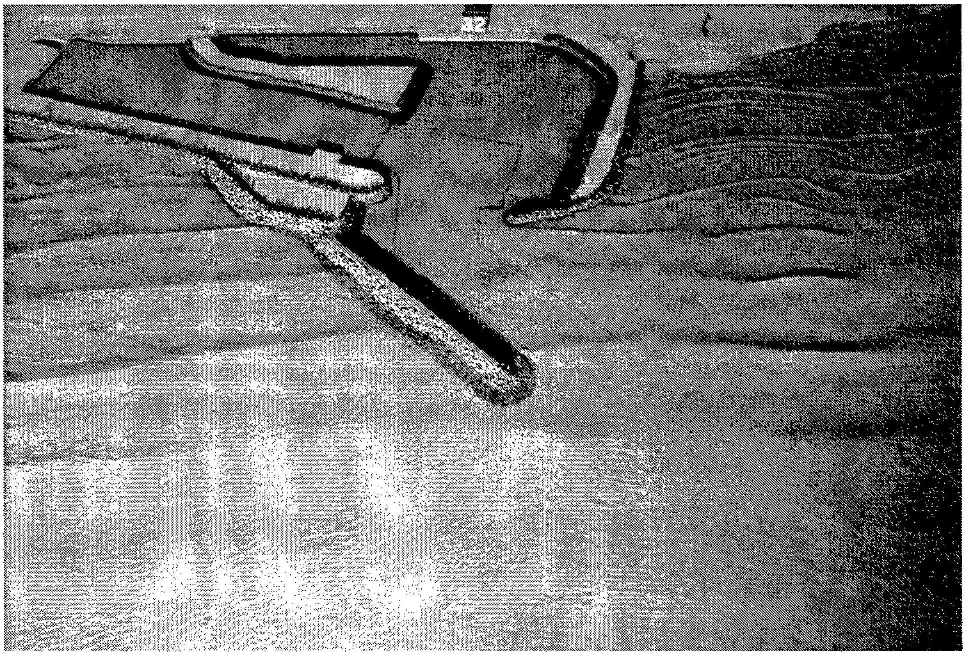


Photo 13. Typical wave patterns for Alternative 1; 8-sec, 3-ft waves from 160 deg; swl = +1.0 ft mllw

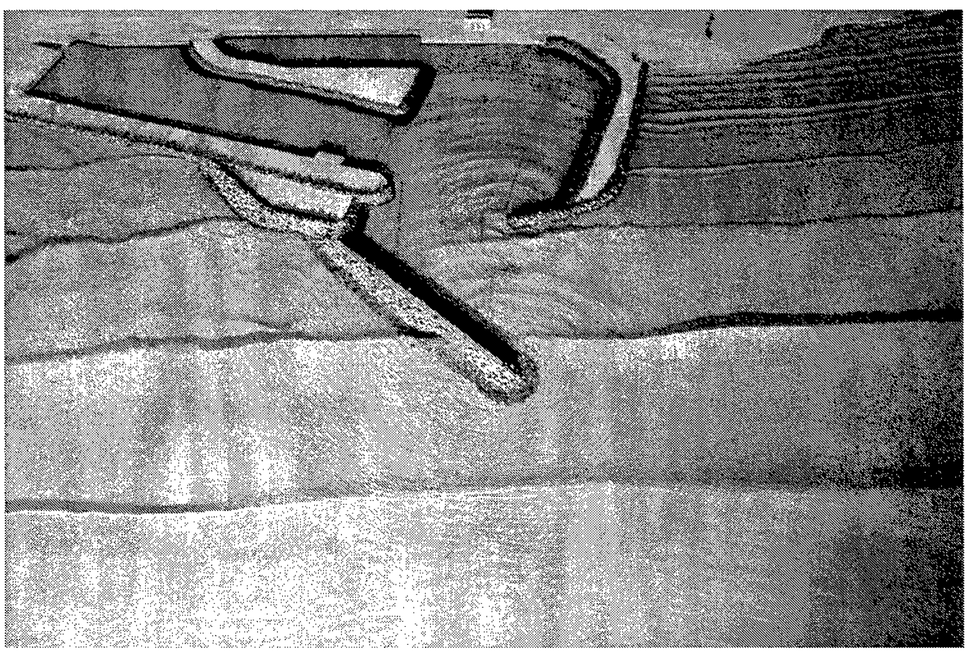


Photo 14. Typical wave patterns for Alternative 1; 14-sec, 6-ft waves from 160 deg; swl = +1.0 ft mllw

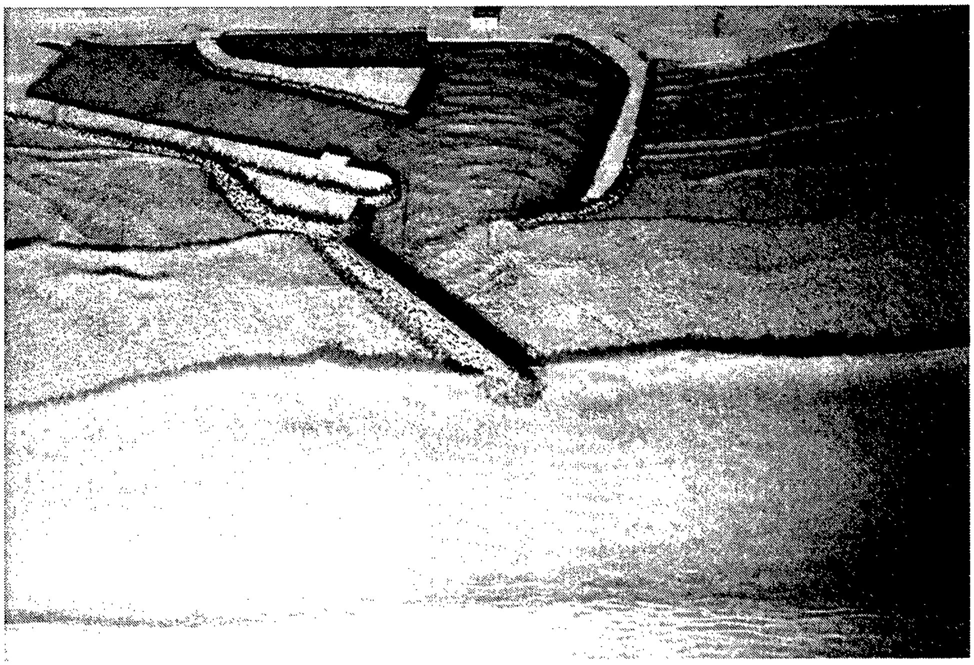


Photo 15. Typical wave patterns for Alternative 1; 18-sec, 8-ft waves from 160 deg; swl = +1.0 ft mllw

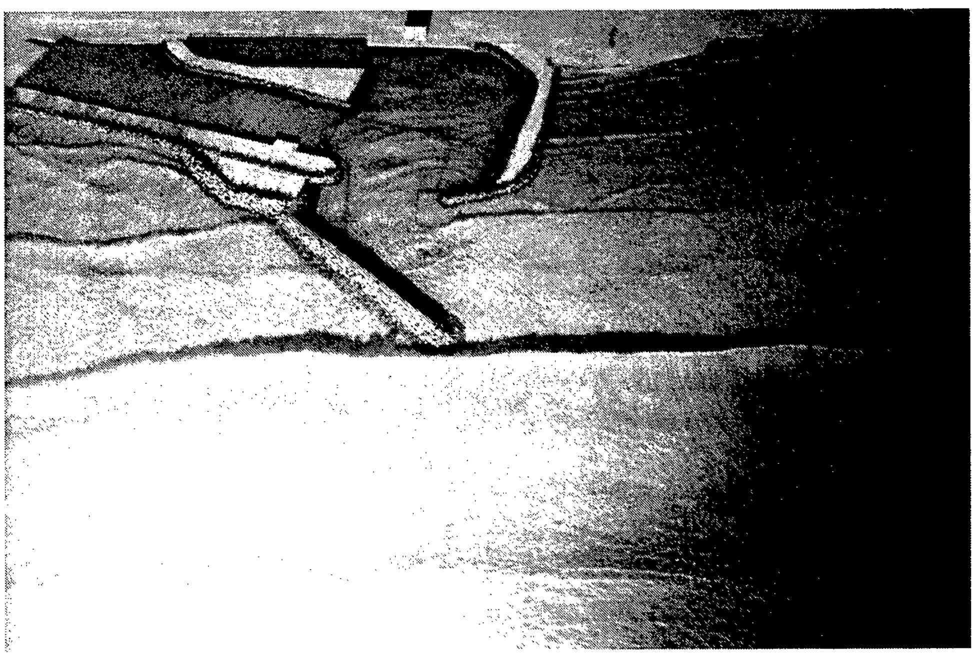


Photo 16. Typical wave patterns for Alternative 1; 18-sec, 8-ft waves from 160 deg; swl = +2.3 ft mllw

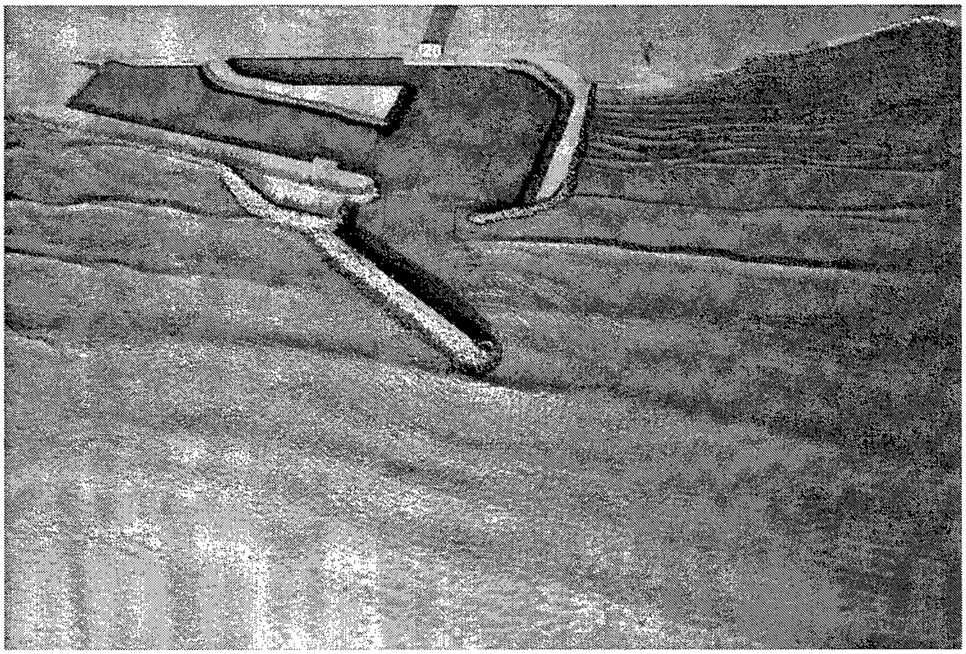


Photo 17. Typical wave patterns for Alternative 1; 8-sec, 3-ft waves from 180 deg; swl = +1.0 ft mllw

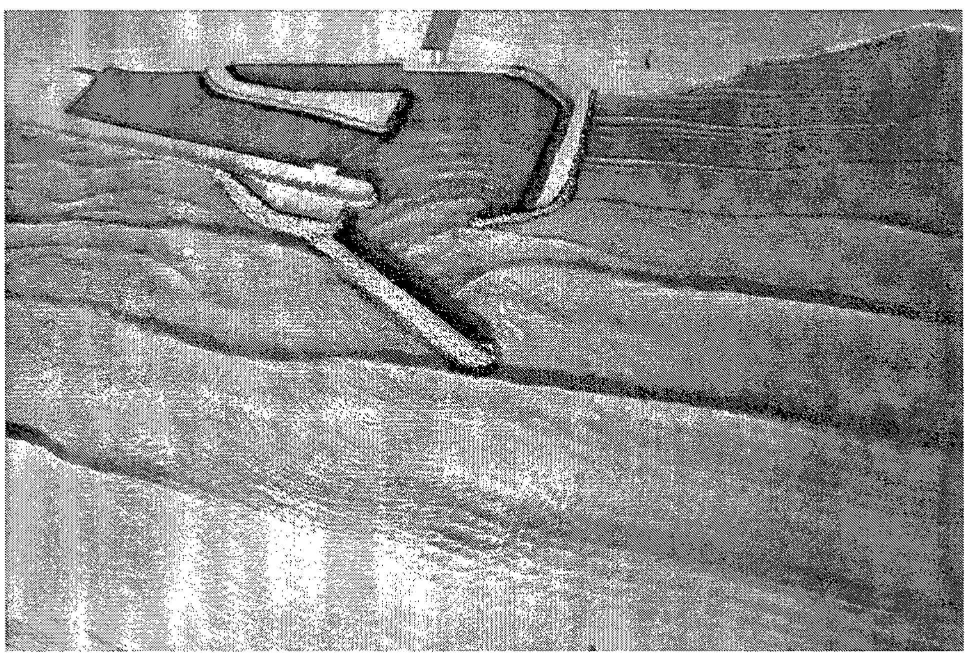


Photo 18. Typical wave patterns for Alternative 1; 14-sec, 6-ft waves from 180 deg; swl = +1.0 ft mllw

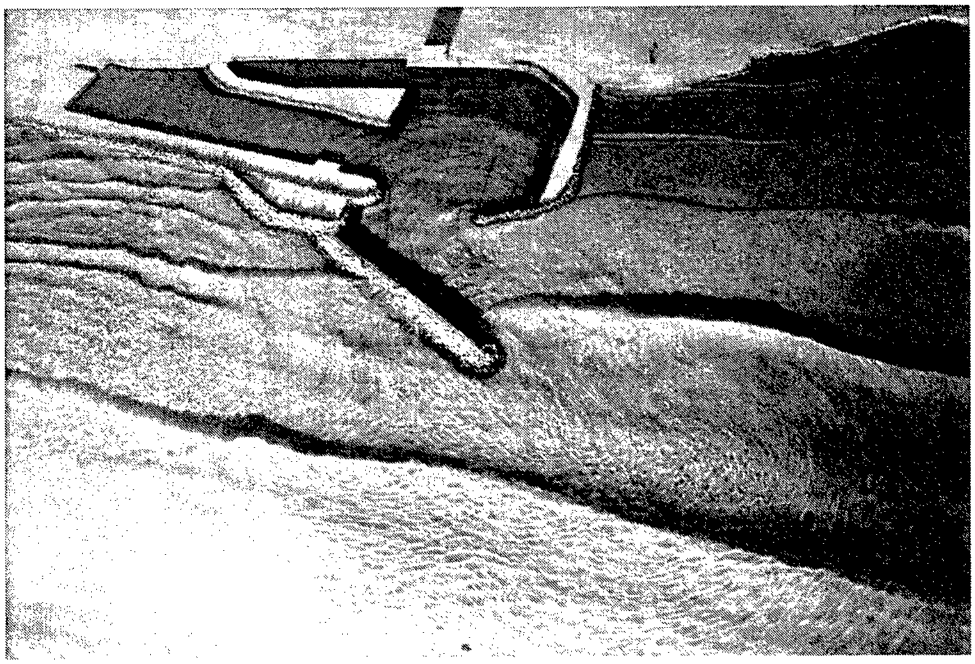


Photo 19. Typical wave patterns for Alternative 1; 18-sec, 8-ft waves from 180 deg; swl = +1.0 ft mllw

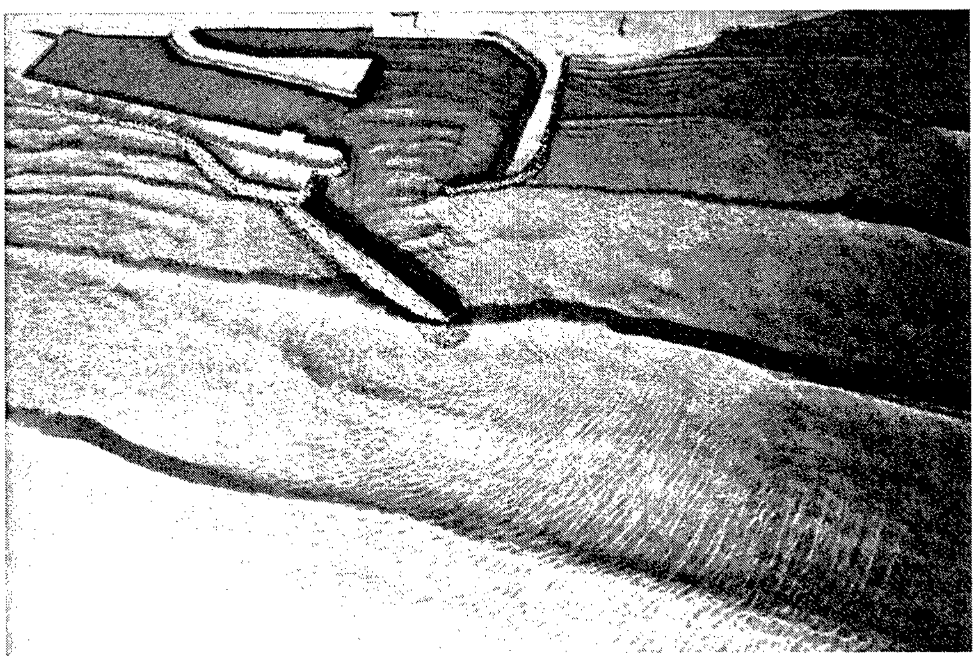


Photo 20. Typical wave patterns for Alternative 1; 18-sec, 8-ft waves from 180 deg; swl = +2.3 ft mllw

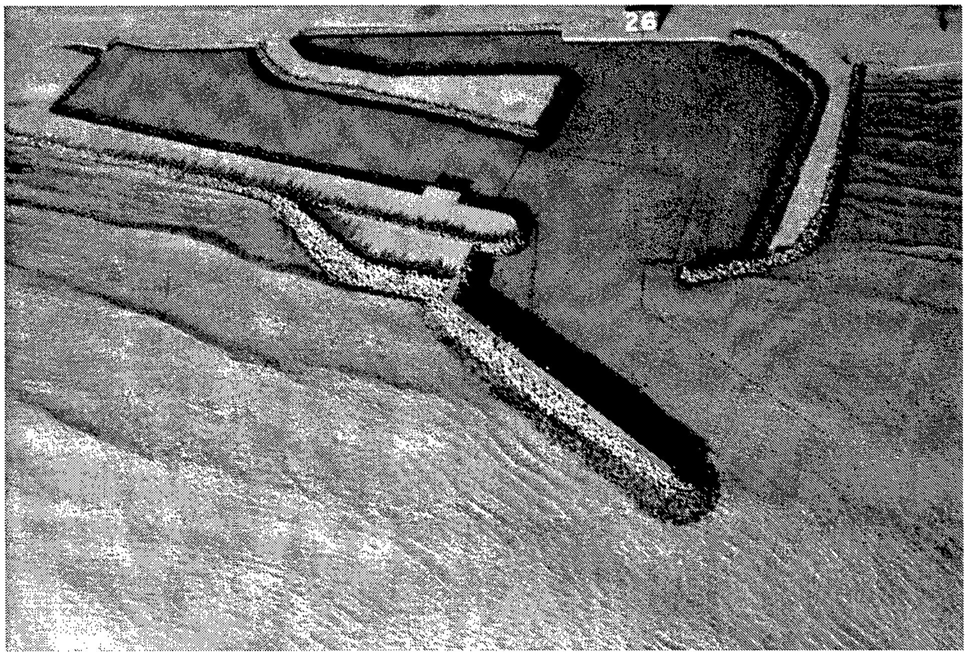


Photo 21. Typical wave patterns for Alternative 1; 8-sec, 3-ft waves from 215 deg; swl = +1.0 ft mllw

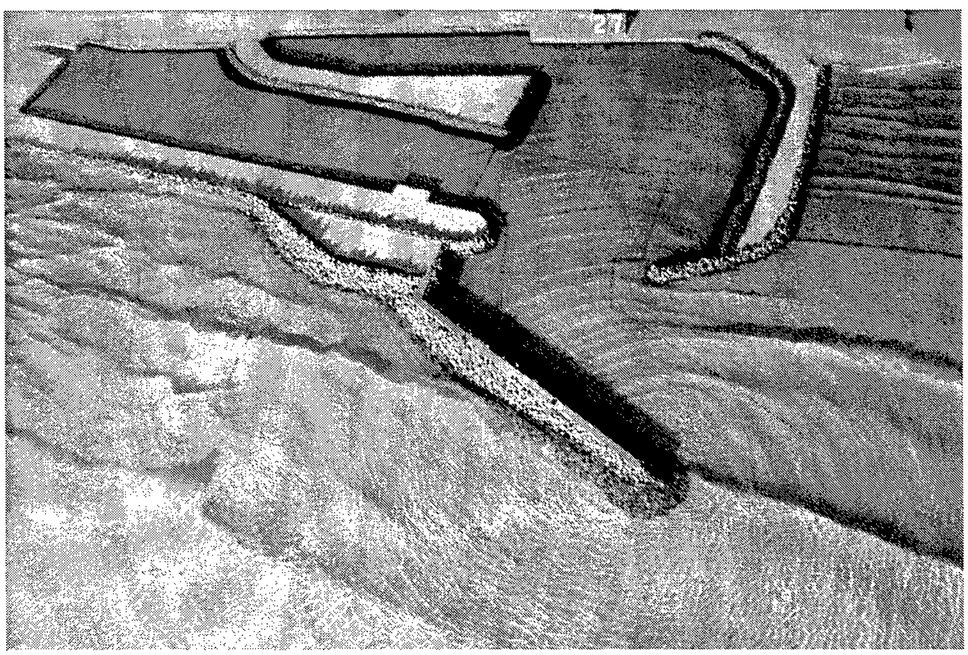


Photo 22. Typical wave patterns for Alternative 1; 14-sec, 6-ft waves from 215 deg; swl = +1.0 ft mllw

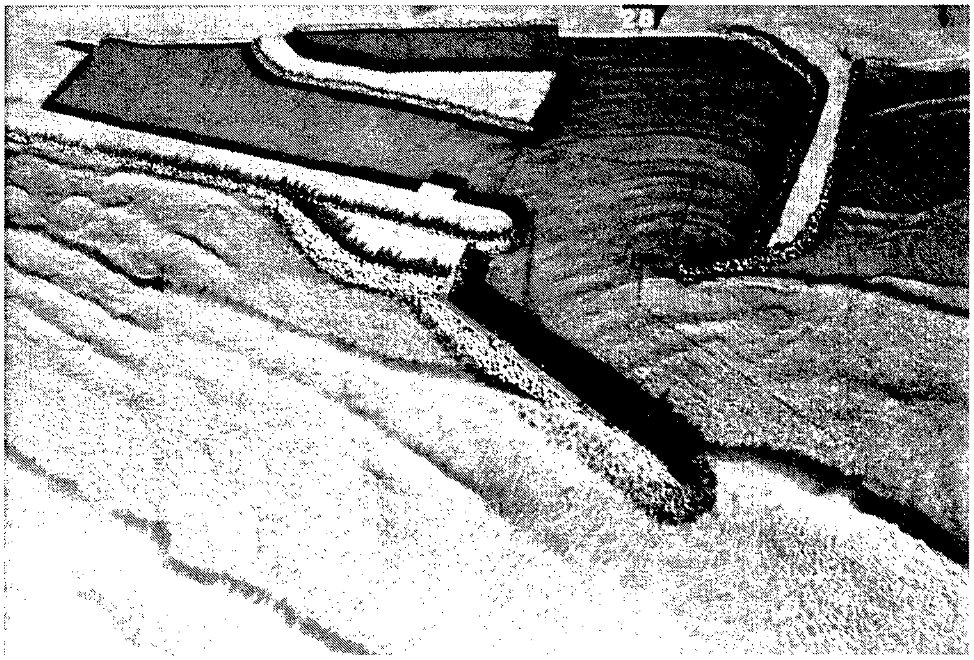


Photo 23. Typical wave patterns for Alternative 1; 18-sec, 8-ft waves from 215 deg; swl = +1.0 ft mllw

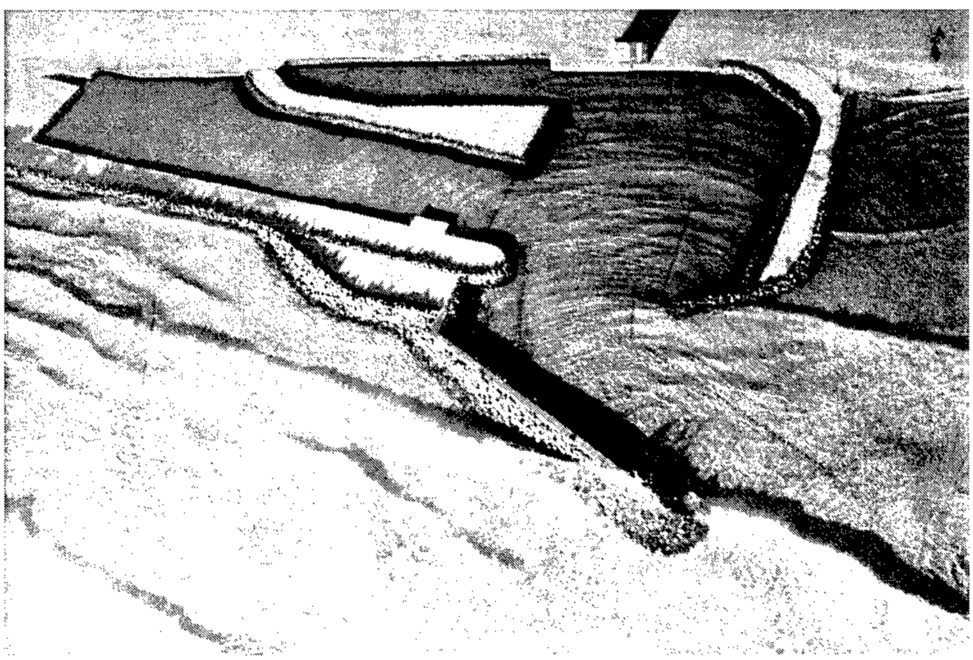


Photo 24. Typical wave patterns for Alternative 1; 18-sec, 8-ft waves from 215 deg; swl = +2.3 ft mllw

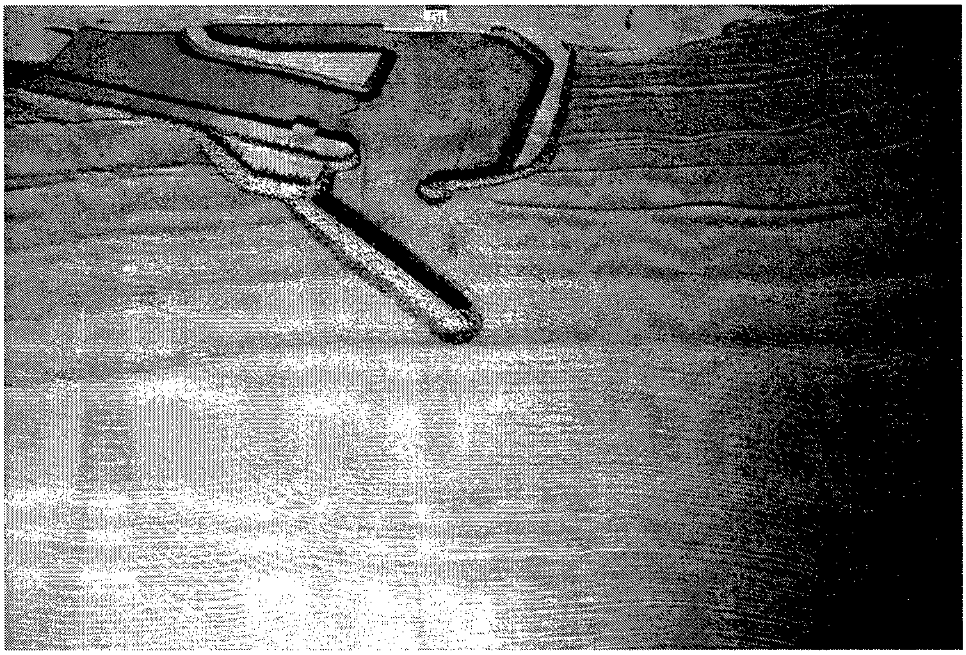


Photo 25. Typical wave patterns for Alternative 1a; 8-sec, 3-ft waves from 160 deg; swl = +1.0 ft mllw

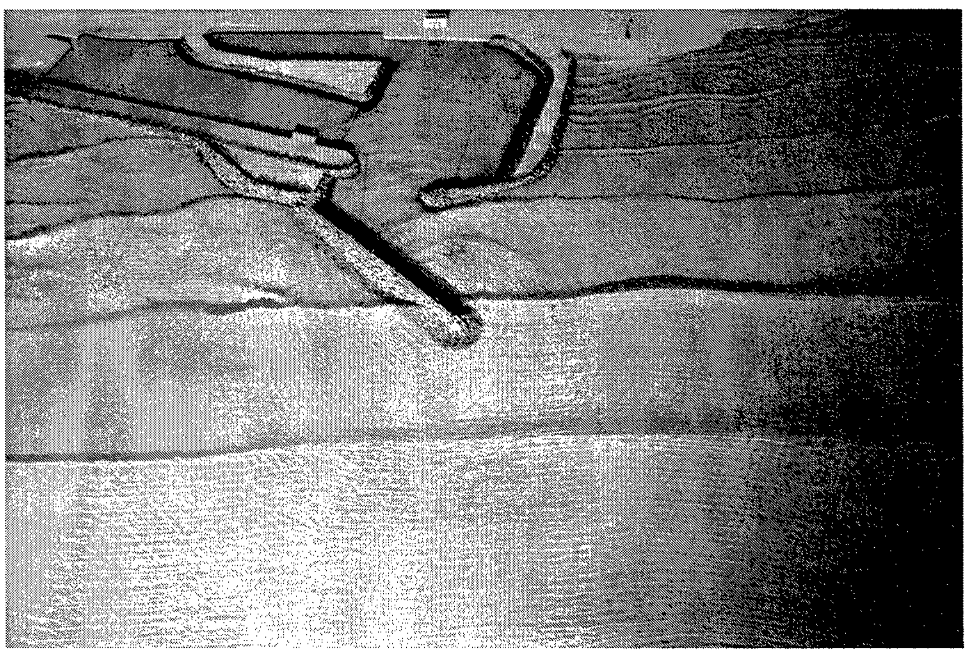


Photo 26. Typical wave patterns for Alternative 1a; 14-sec, 6-ft waves from 160 deg; swl = +1.0 ft mllw

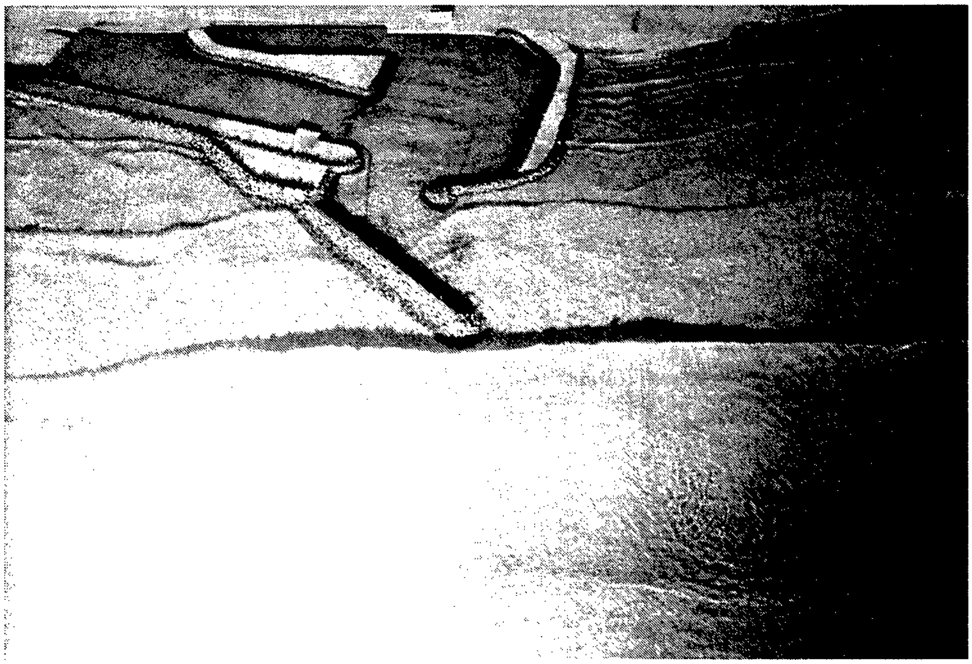


Photo 27. Typical wave patterns for Alternative 1a; 18-sec, 8-ft waves from 160 deg; swl = +1.0 ft mllw

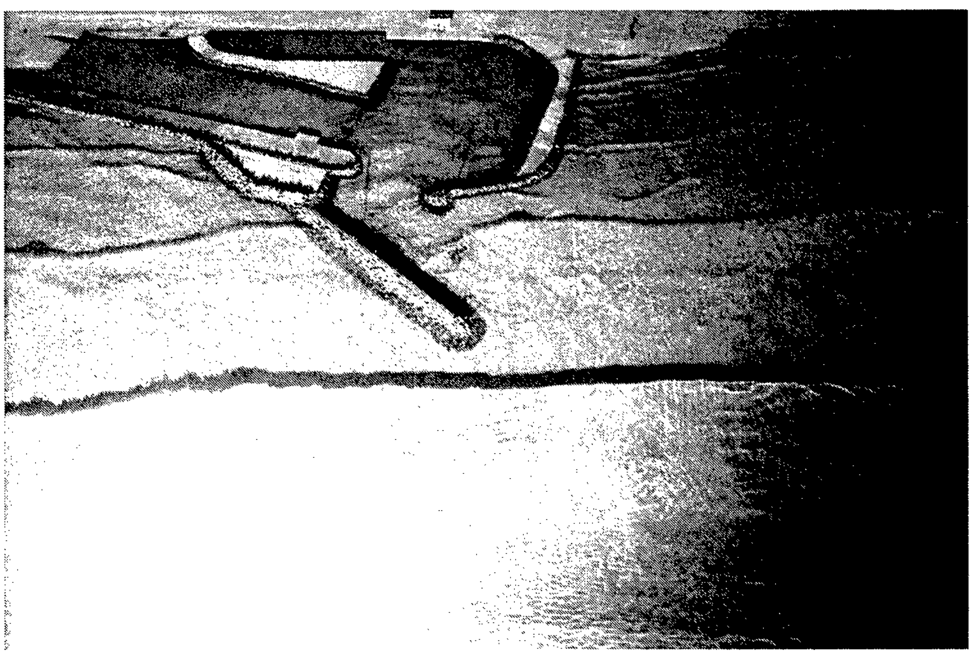


Photo 28. Typical wave patterns for Alternative 1a; 18-sec, 8-ft waves from 160 deg; swl = +2.3 ft mllw

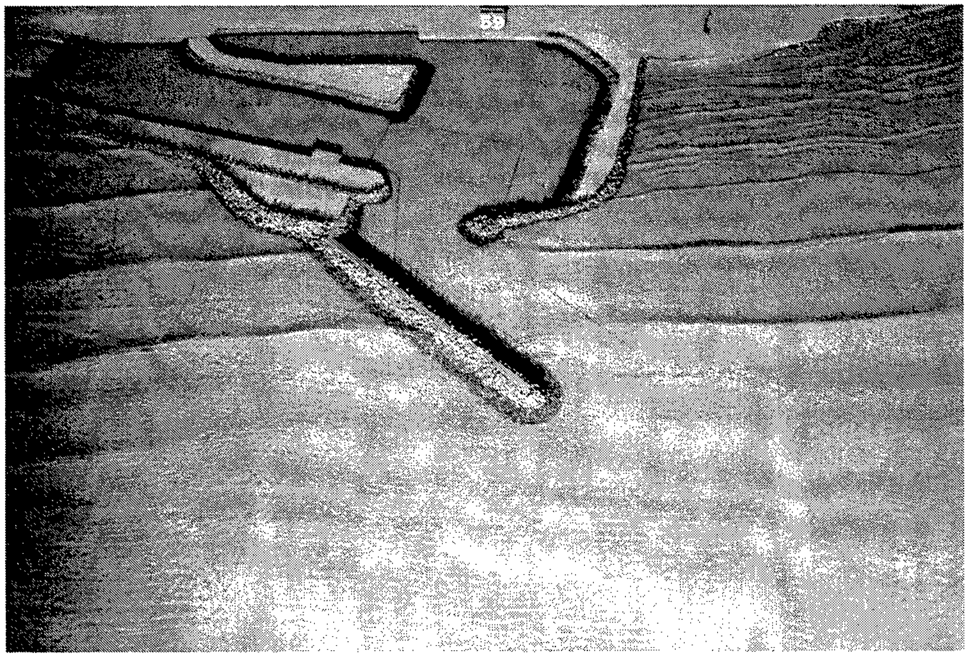


Photo 29. Typical wave patterns for Alternative 1c; 8-sec, 3-ft waves from 160 deg; swl = +1.0 ft mllw

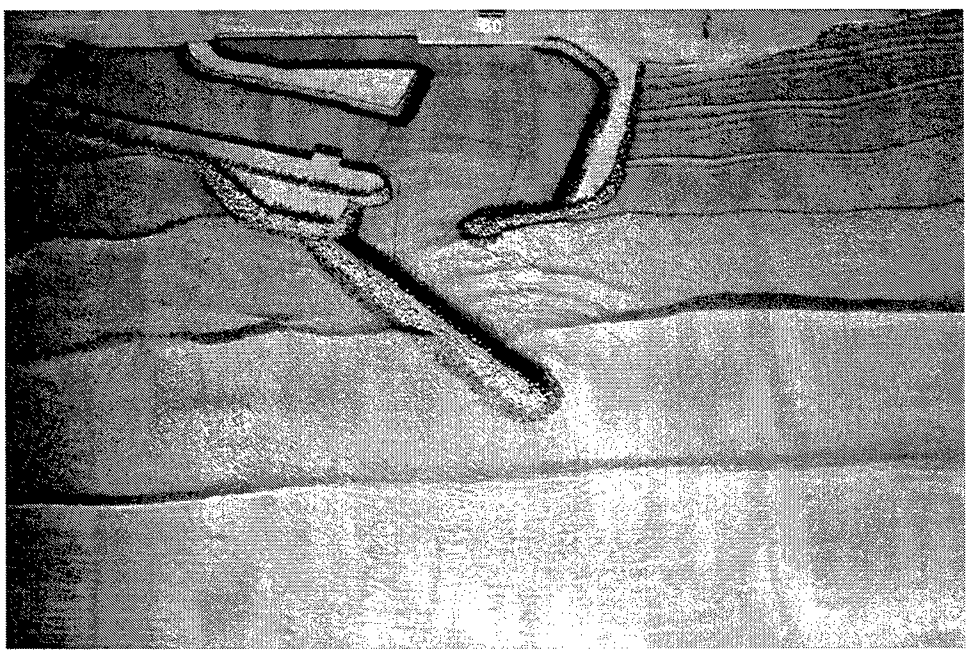


Photo 30. Typical wave patterns for Alternative 1c; 14-sec, 6-ft waves from 160 deg; swl = +1.0 ft mllw

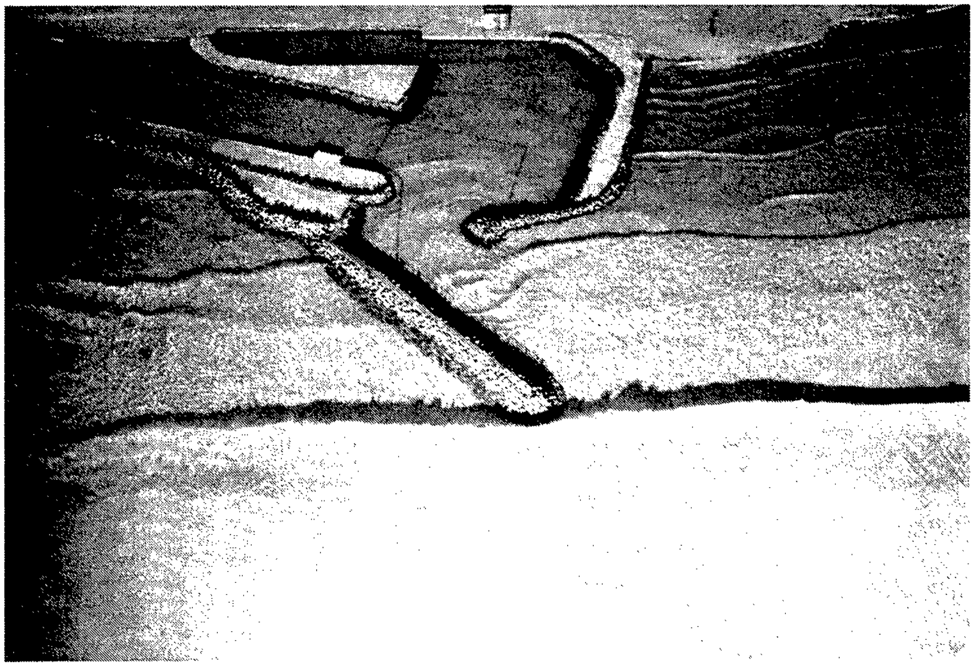


Photo 31. Typical wave patterns for Alternative 1c; 18-sec, 8-ft waves from 160 deg; swl = +1.0 ft mllw

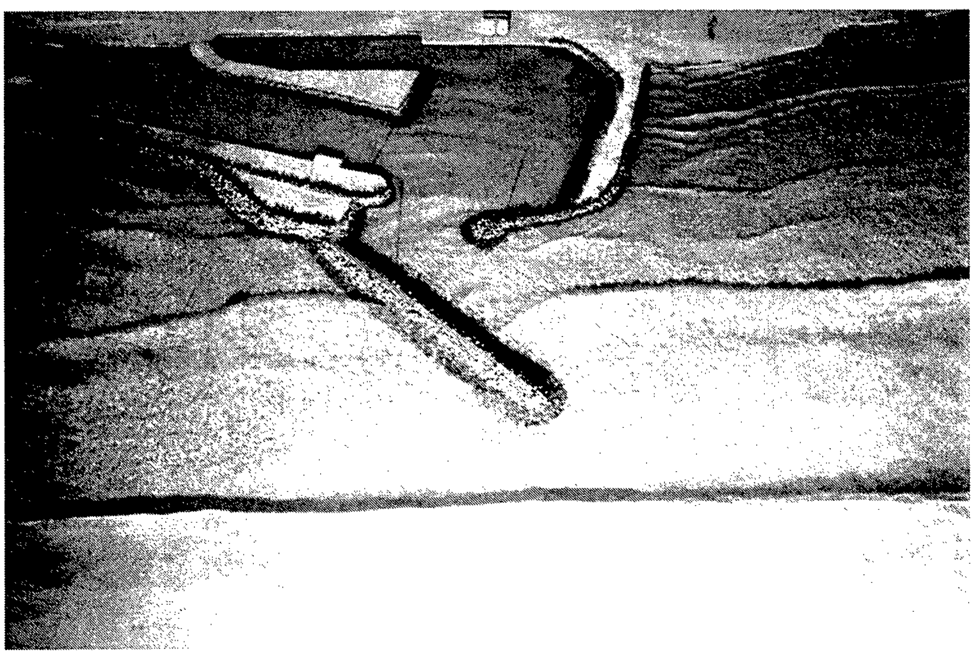


Photo 32. Typical wave patterns for Alternative 1c; 18-sec, 8-ft waves from 160 deg; swl = +2.3 ft mllw

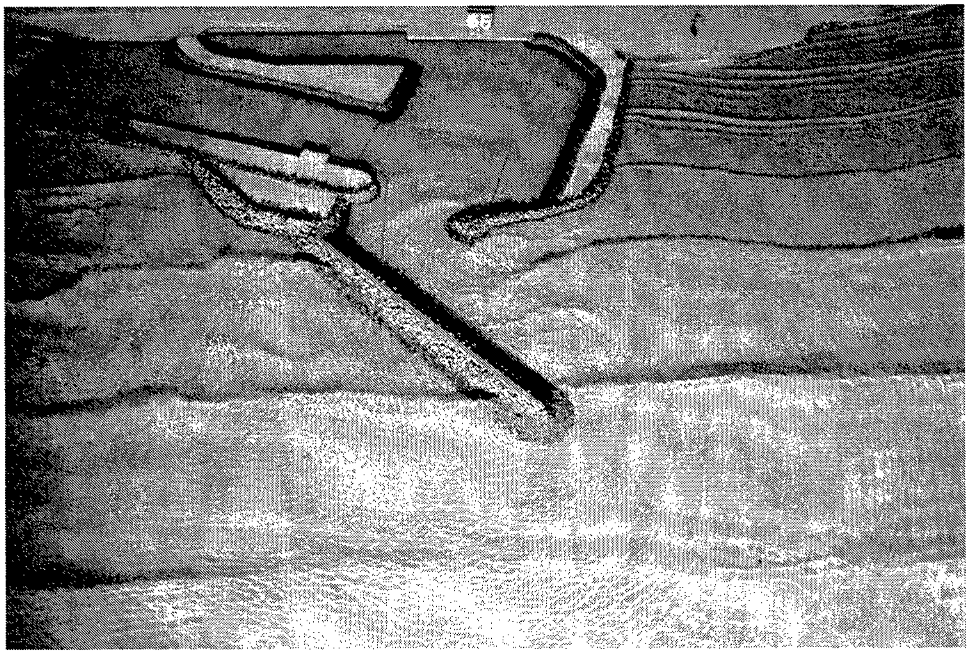


Photo 33. Typical wave patterns for Alternative 1d; 8-sec, 3-ft waves from 160 deg; swl = +1.0 ft mllw

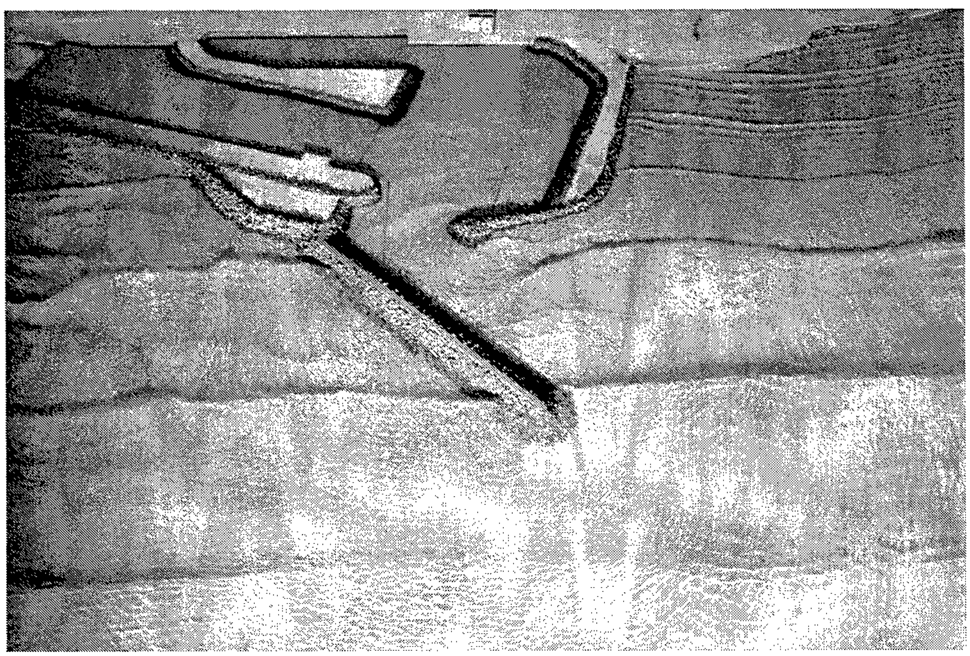


Photo 34. Typical wave patterns for Alternative 1d; 14-sec, 6-ft waves from 160 deg; swl = +1.0 ft mllw

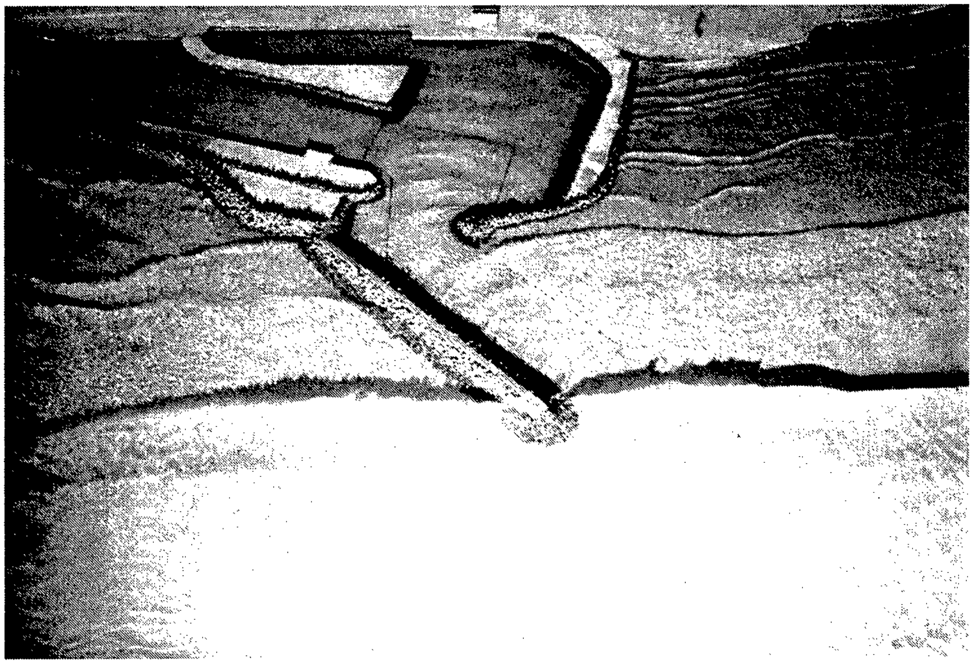


Photo 35. Typical wave patterns for Alternative 1d; 18-sec, 8-ft waves from 160 deg; swl = +1.0 ft mllw

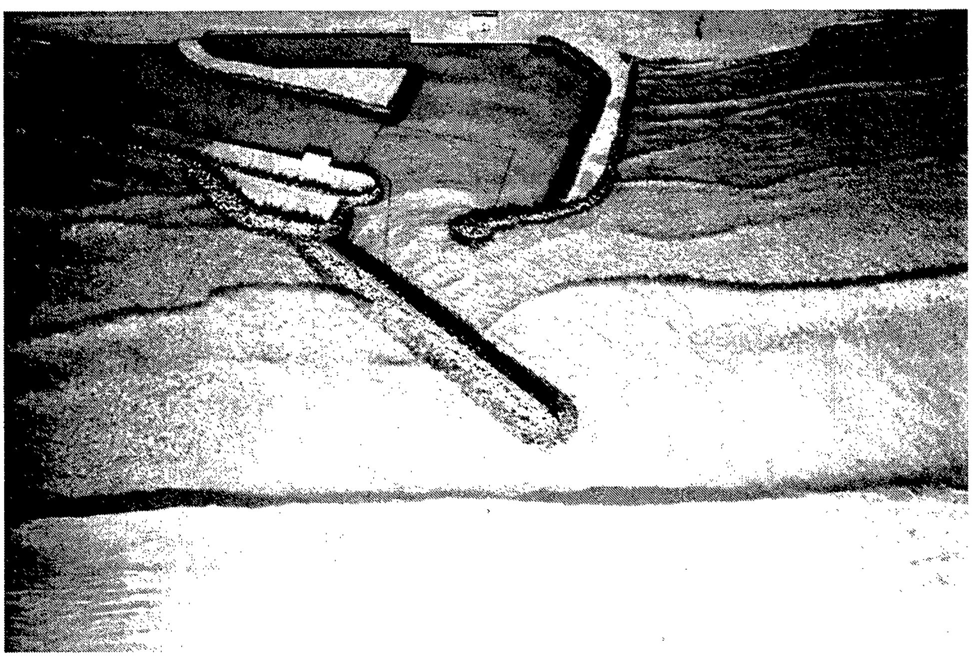


Photo 36. Typical wave patterns for Alternative 1d; 18-sec, 8-ft waves from 160 deg; swl = +2.3 ft mllw

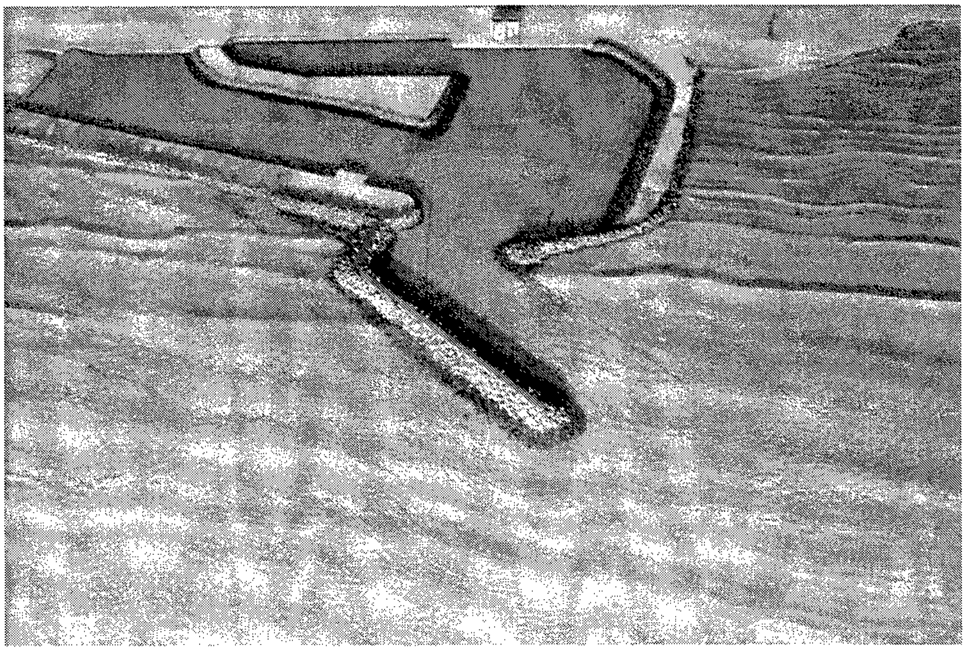


Photo 37. Typical wave patterns for Alternative 2a; 8-sec, 8-ft waves from 180 deg; swl = +1.0 ft mllw

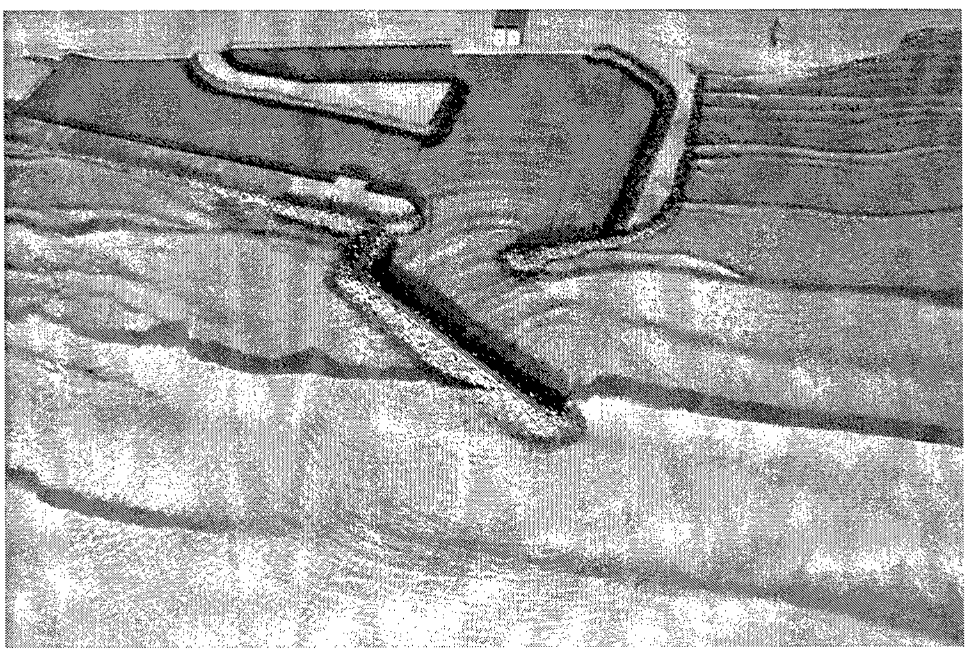


Photo 38. Typical wave patterns for Alternative 2a; 14-sec, 6-ft waves from 180 deg; swl = +1.0 ft mllw

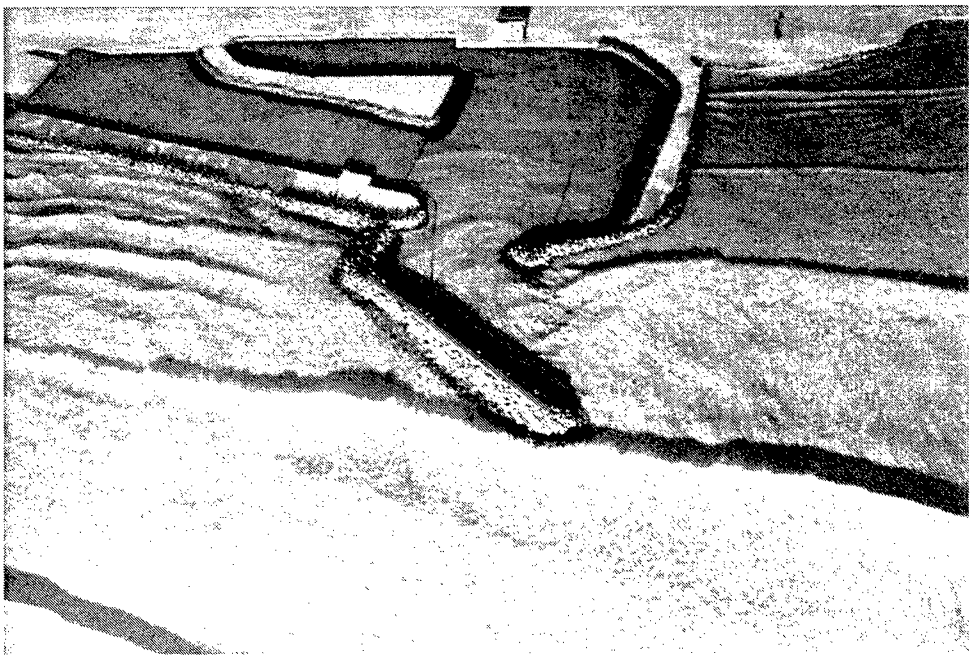


Photo 39. Typical wave patterns for Alternative 2a; 18-sec, 8-ft waves from 180 deg; swl = +1.0 ft mllw

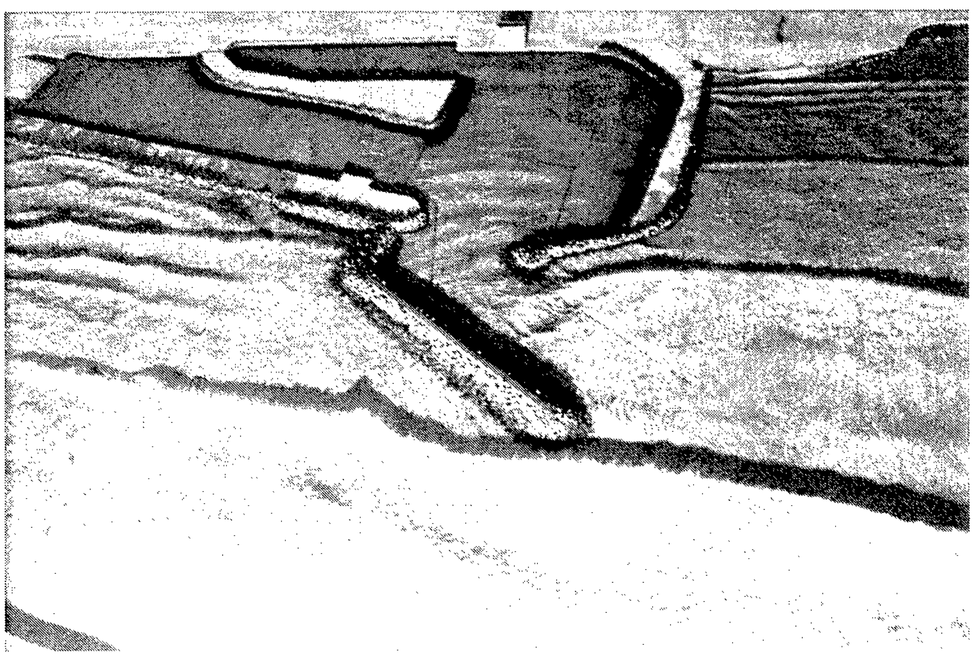


Photo 40. Typical wave patterns for Alternative 2a; 18-sec, 8-ft waves from 180 deg; swl = +2.3 ft mllw

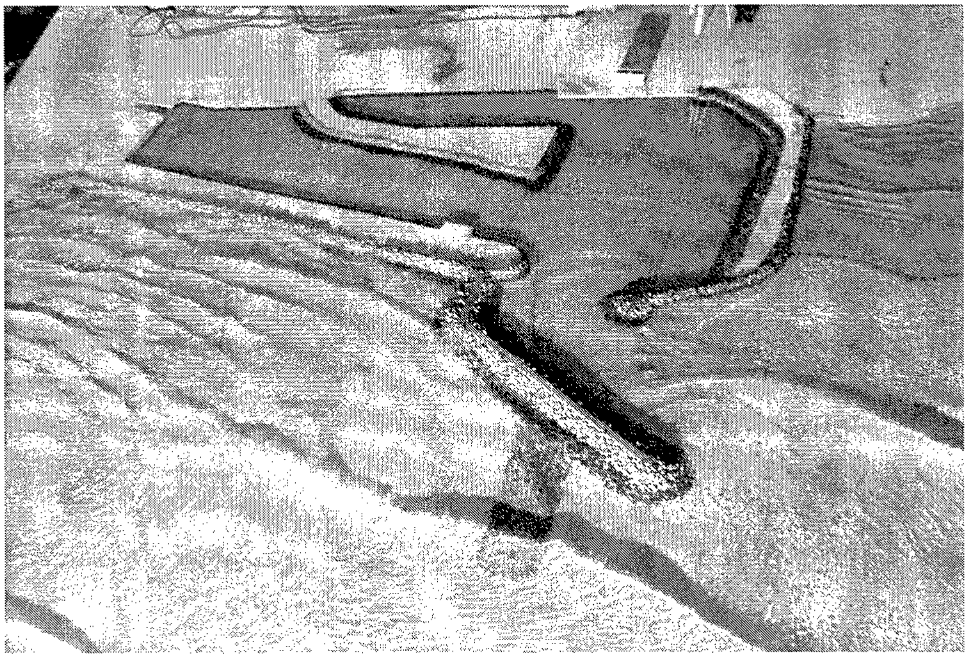


Photo 41. Typical wave patterns for Alternative 2a; 18-sec, 8-ft waves from 215 deg; swl = +1.0 ft mllw

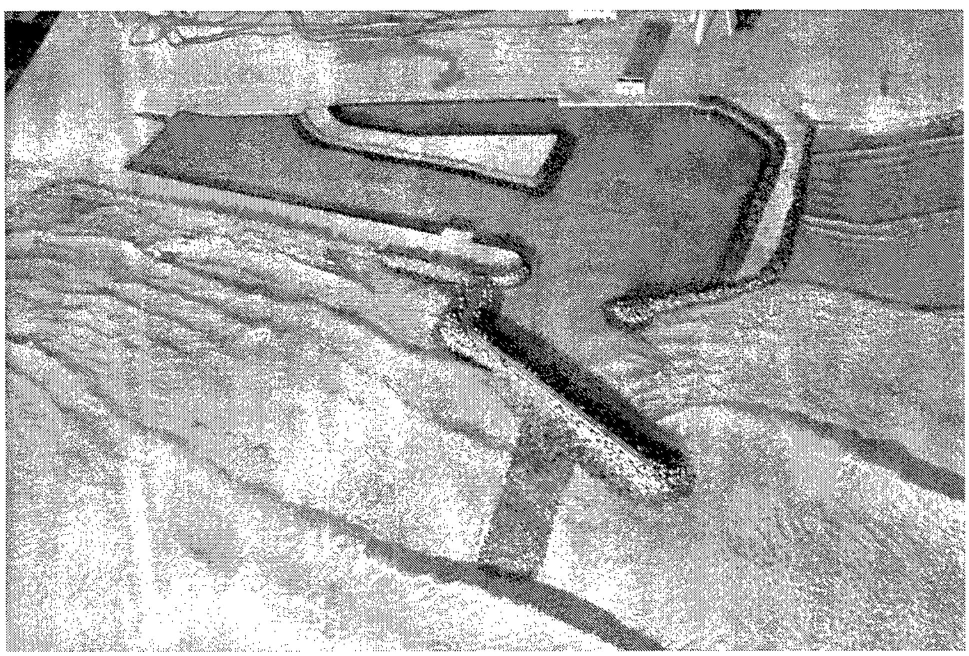


Photo 42. Typical wave patterns for Alternative 2a; 18-sec, 8-ft waves from 215 deg; swl = +2.3 ft mllw

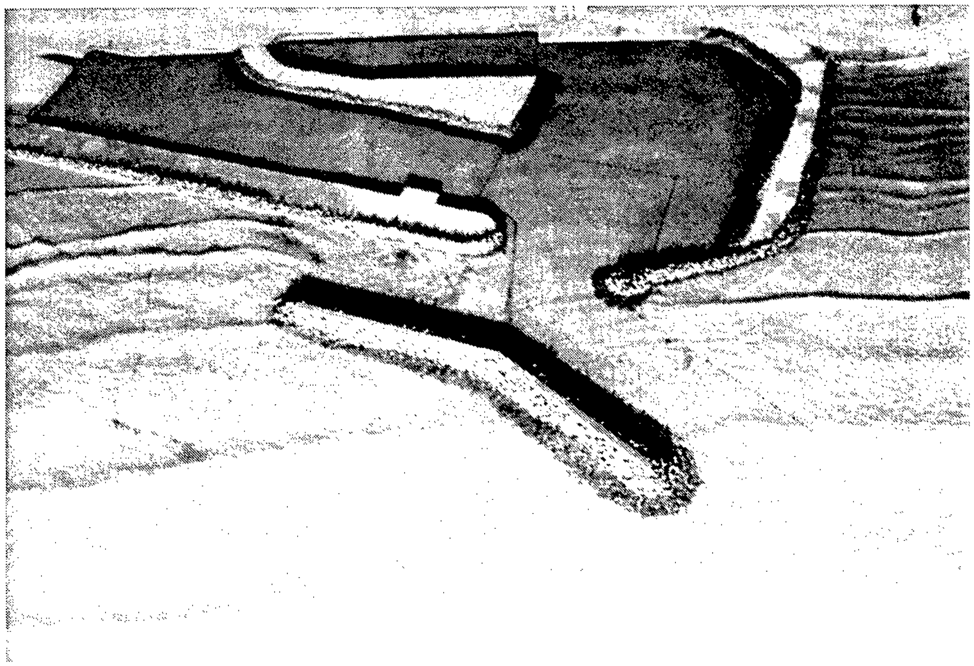


Photo 43. Typical wave patterns for Alternative 3a; 8-sec, 3-ft waves from 160 deg; swl = +1.0 ft mllw

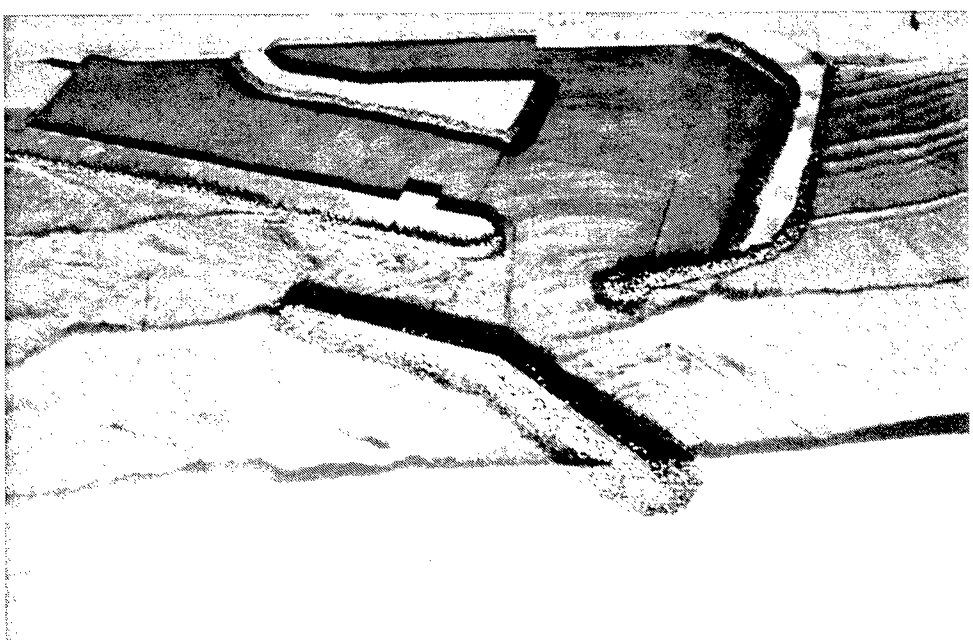


Photo 44. Typical wave patterns for Alternative 3a; 14-sec, 6-ft waves from 160 deg; swl = +1.0 ft mllw

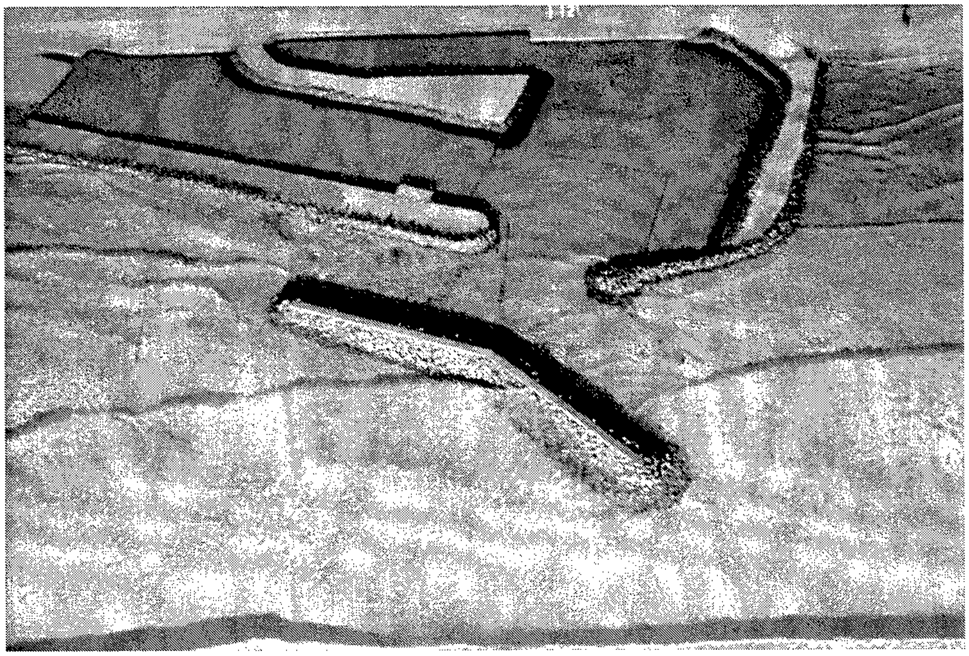


Photo 45. Typical wave patterns for Alternative 3a; 18-sec, 8-ft waves from 160 deg; swl = +1.0 ft mllw

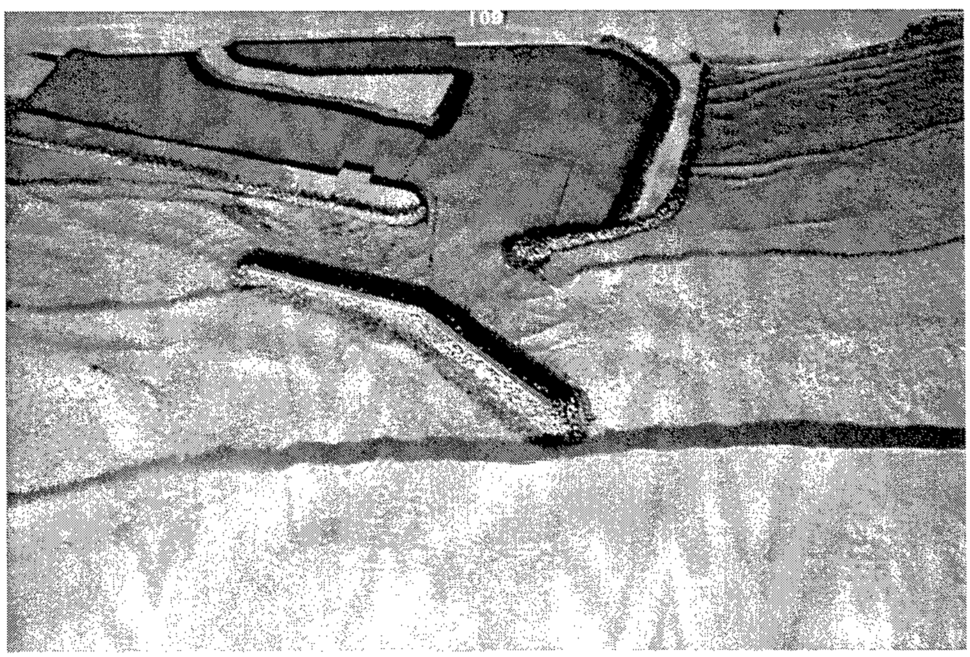


Photo 46. Typical wave patterns for Alternative 3a; 18-sec, 8-ft waves from 160 deg; swl = +2.3 ft mllw

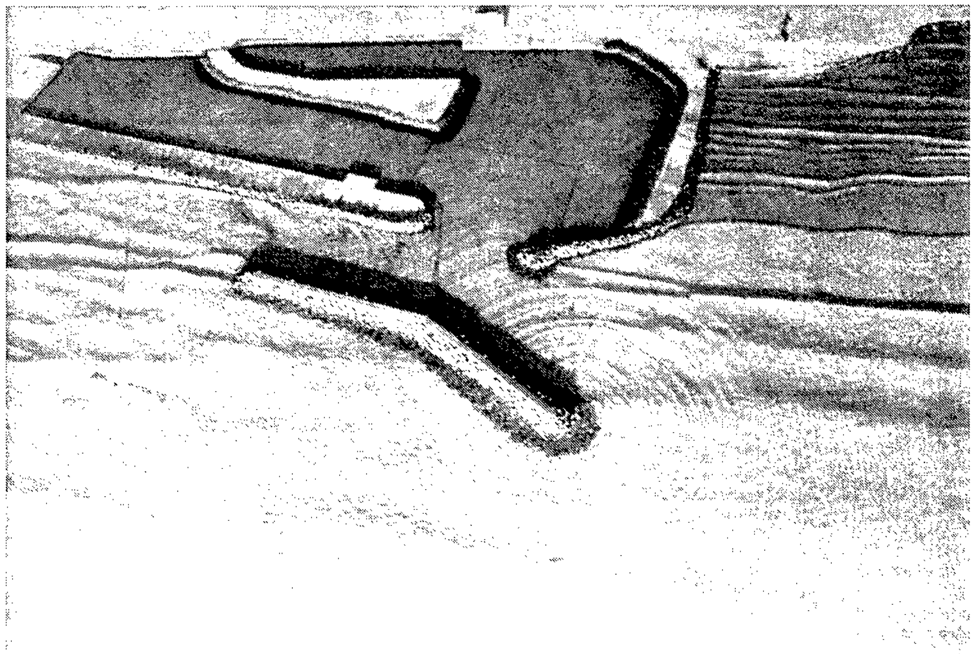


Photo 47. Typical wave patterns for Alternative 3a; 8-sec, 3-ft waves from 180 deg; swl = +1.0 ft mllw

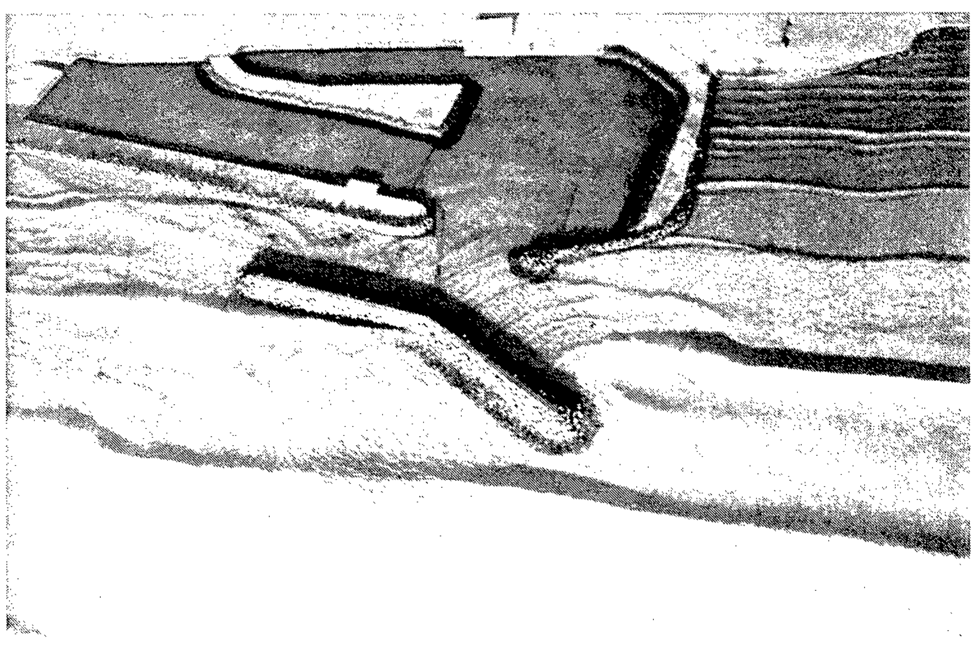


Photo 48. Typical wave patterns for Alternative 3a; 14-sec, 6-ft waves from 180 deg; swl = +1.0 ft mllw

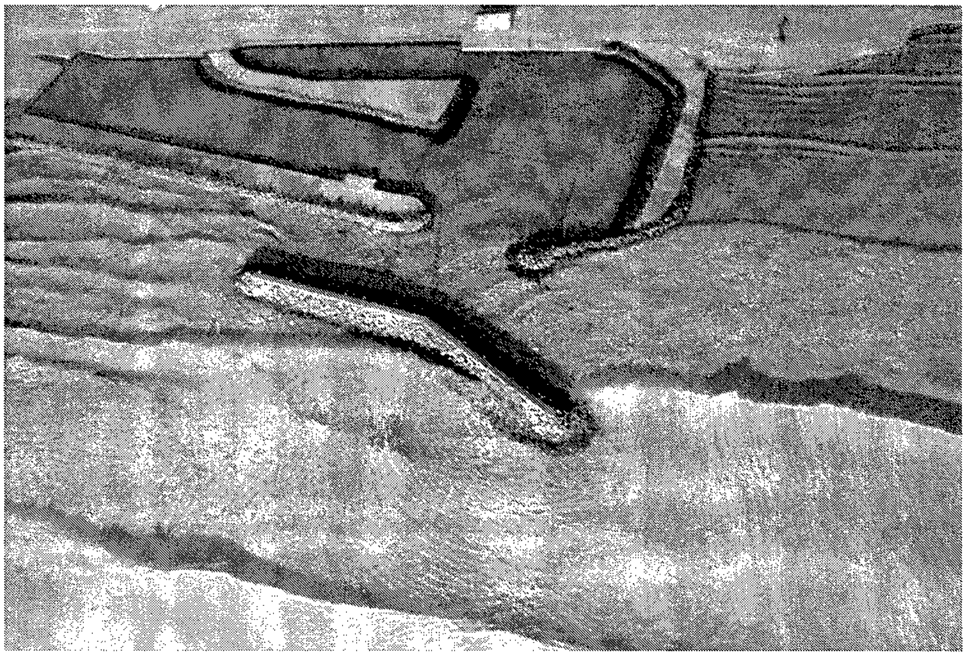


Photo 49. Typical wave patterns for Alternative 3a; 18-sec, 8-ft waves from 180 deg; swl = +1.0 ft mllw

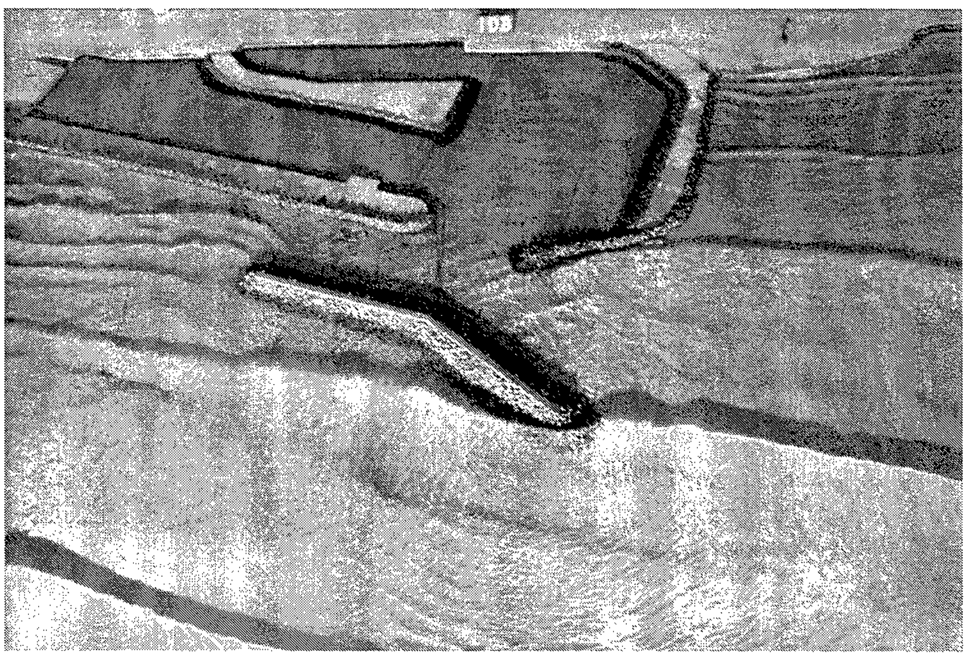


Photo 50. Typical wave patterns for Alternative 3a; 18-sec, 8-ft waves from 180 deg; swl = +2.3 ft mllw

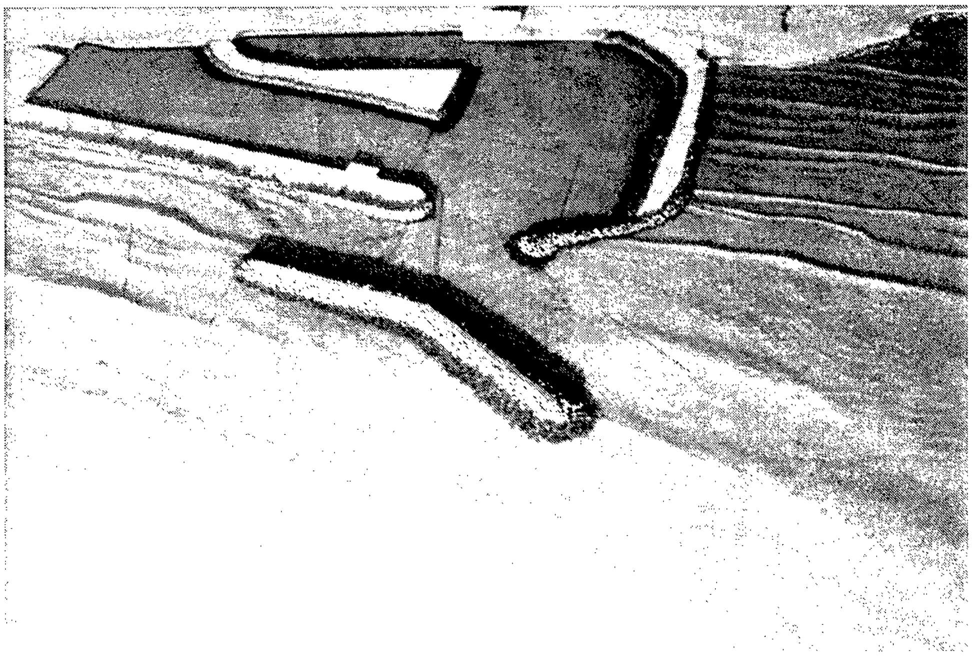


Photo 51. Typical wave patterns for Alternative 3a; 8-sec, 3-ft waves from 215 deg; swl = +1.0 ft mllw

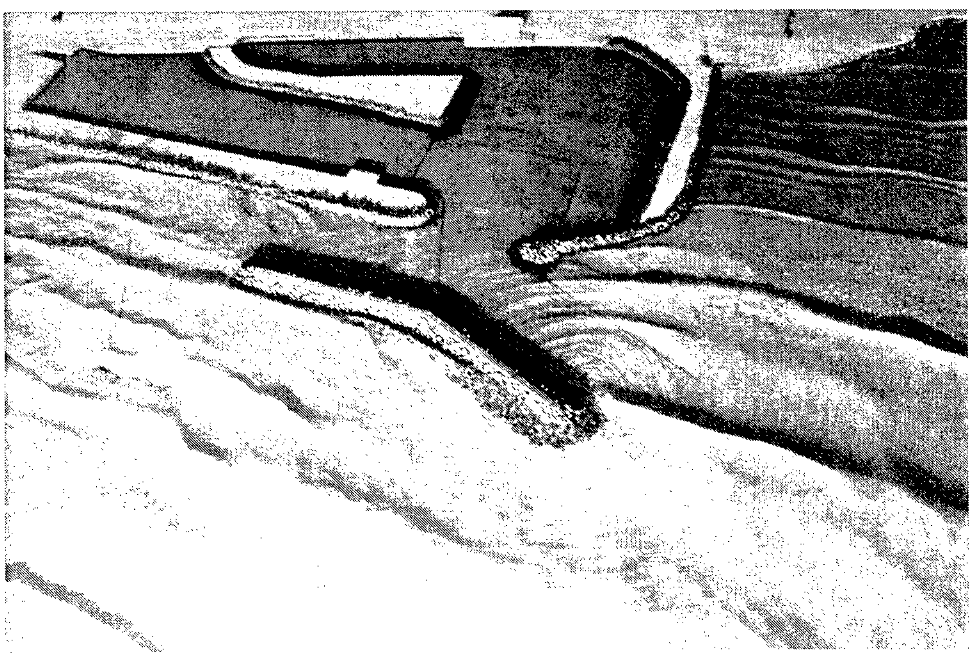


Photo 52. Typical wave patterns for Alternative 3a; 14-sec, 6-ft waves from 215 deg; swl = +1.0 ft mllw

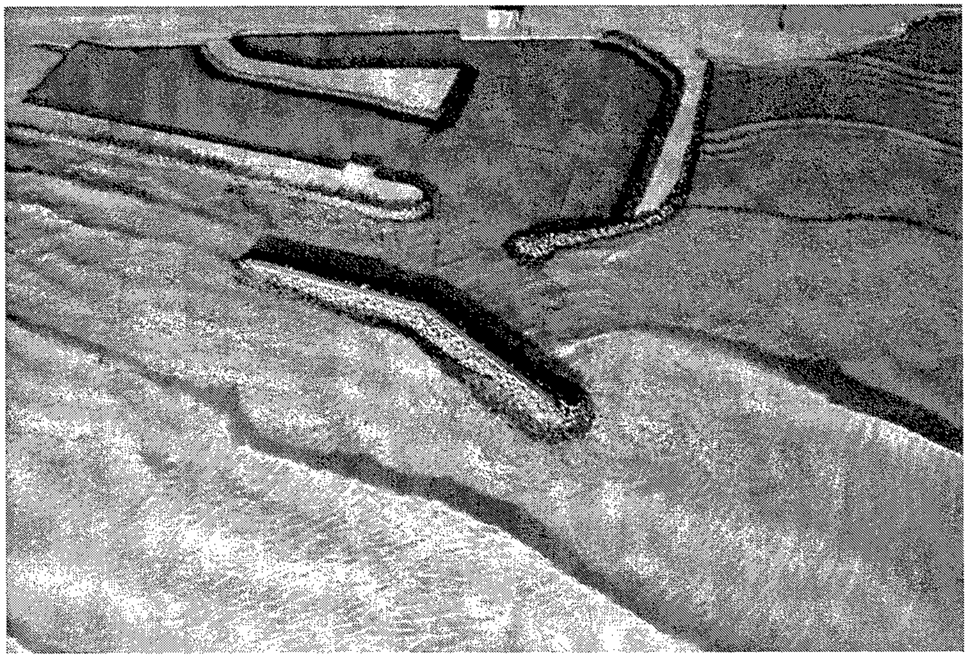


Photo 53. Typical wave patterns for Alternative 3a; 18-sec, 8-ft waves from 215 deg; swl = +1.0 ft mllw

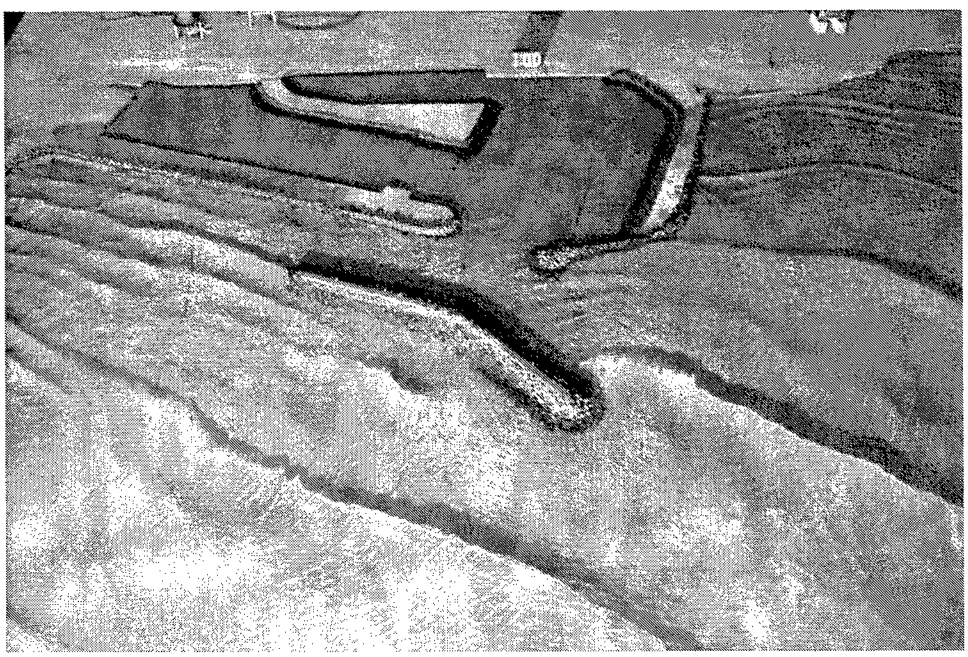


Photo 54. Typical wave patterns for Alternative 3a; 18-sec, 8-ft waves from 215 deg; swl = +2.3 ft mllw

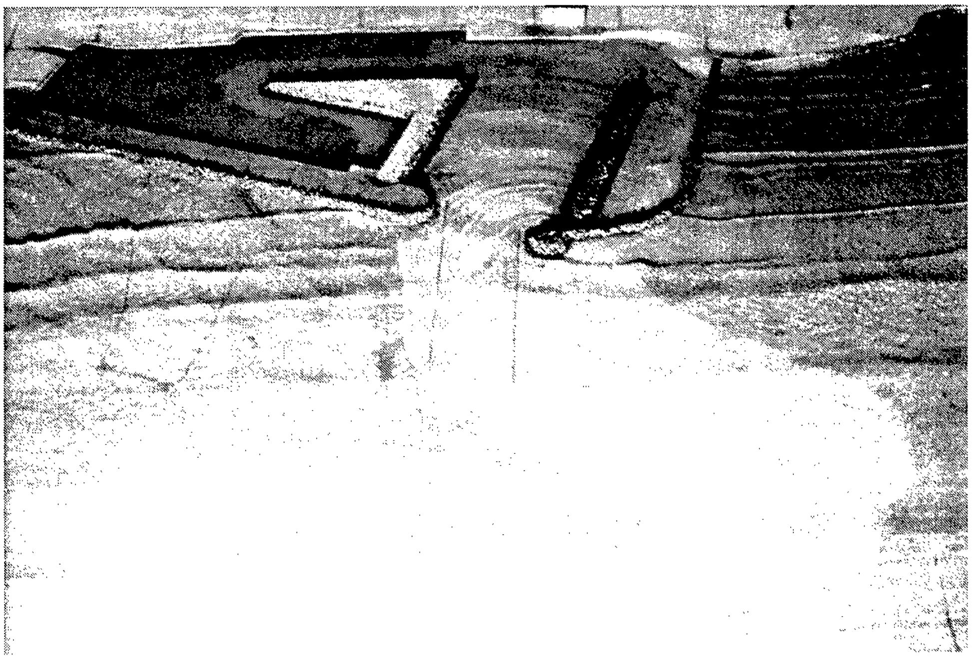


Photo 55. Typical wave patterns for Alternative 8; 8-sec, 3-ft waves from 160 deg; swl = +1.0 ft mllw

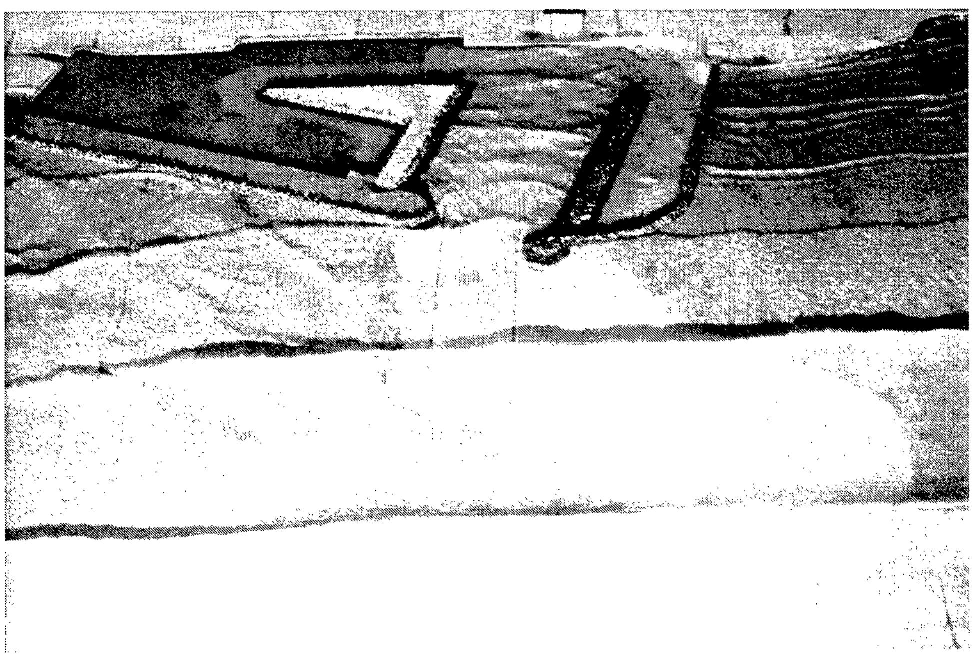


Photo 56. Typical wave patterns for Alternative 8; 14-sec, 6-ft waves from 160 deg; swl = +1.0 ft mllw

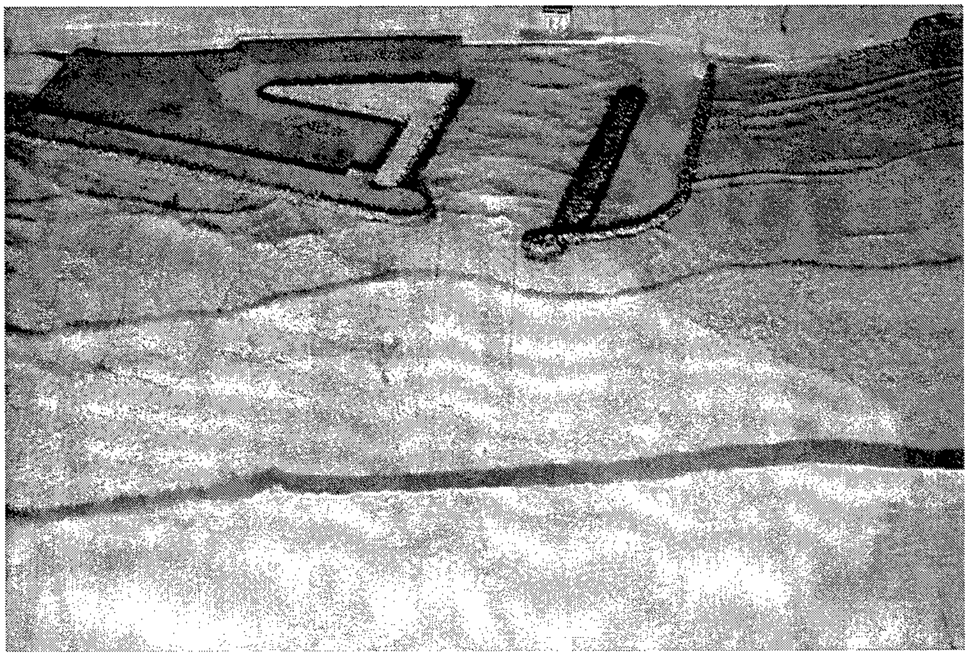


Photo 57. Typical wave patterns for Alternative 8; 18-sec, 8-ft waves from 160 deg; swl = +1.0 ft mllw

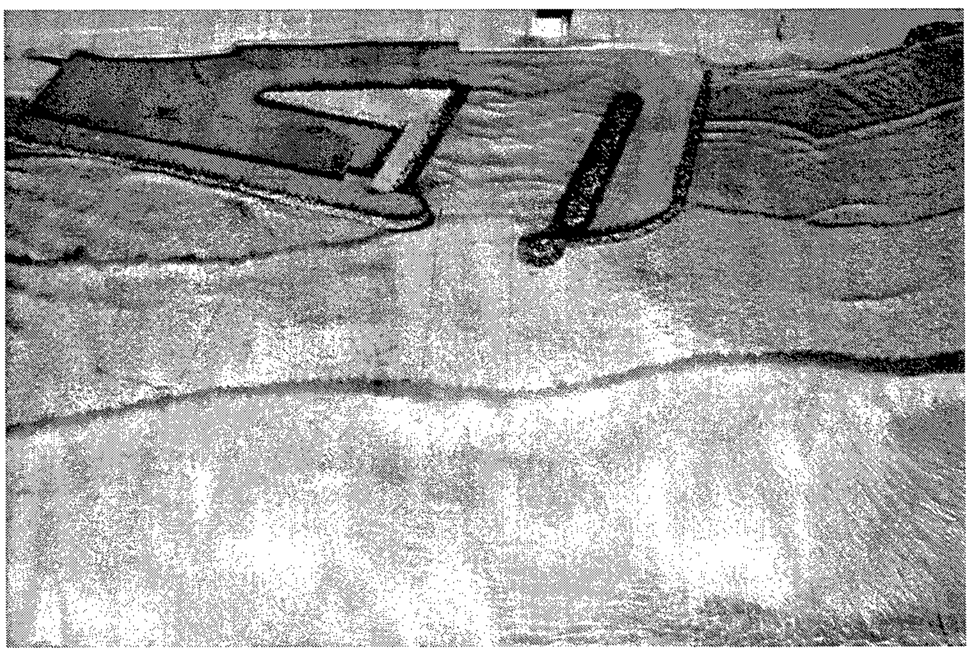


Photo 58. Typical wave patterns for Alternative 8; 18-sec, 8-ft waves from 160 deg; swl = +2.3 ft mllw

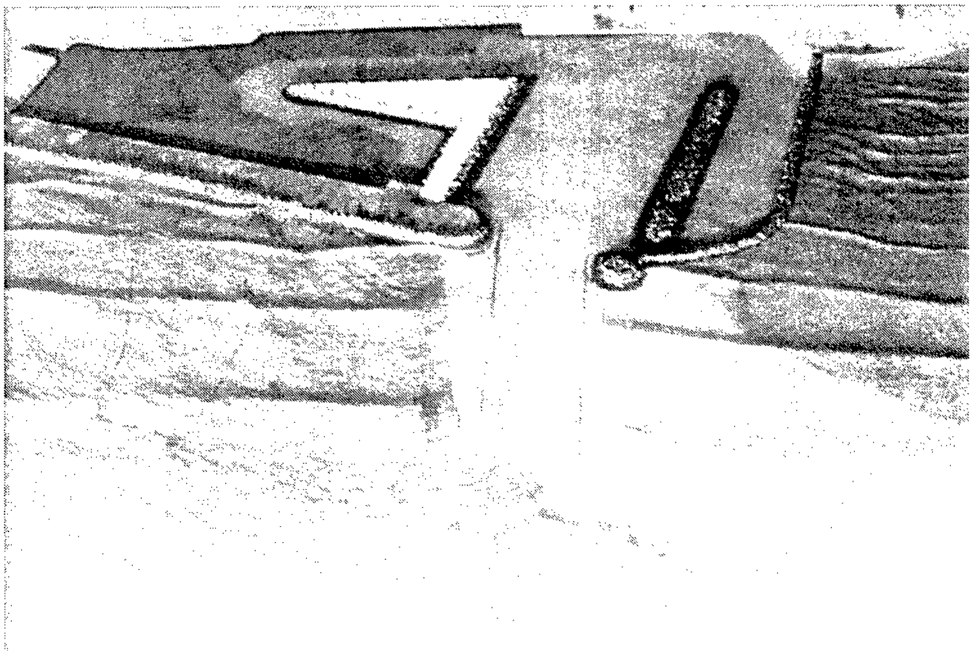


Photo 59. Typical wave patterns for Alternative 8; 8-sec, 3-ft waves from 180 deg; swl = +1.0 ft mllw

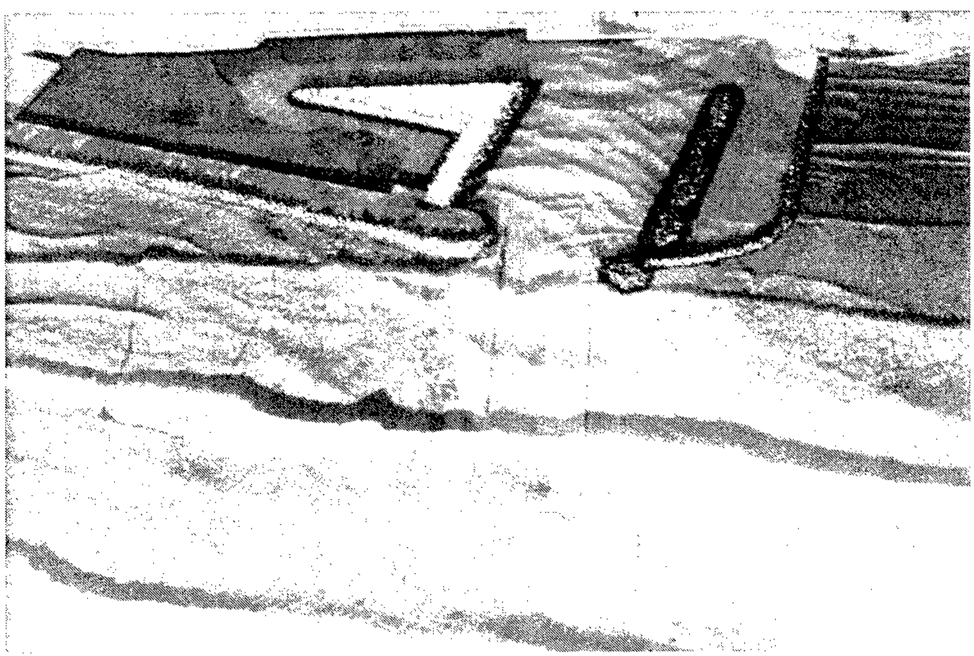


Photo 60. Typical wave patterns for Alternative 8; 14-sec, 6-ft waves from 180 deg; swl = +1.0 ft mllw

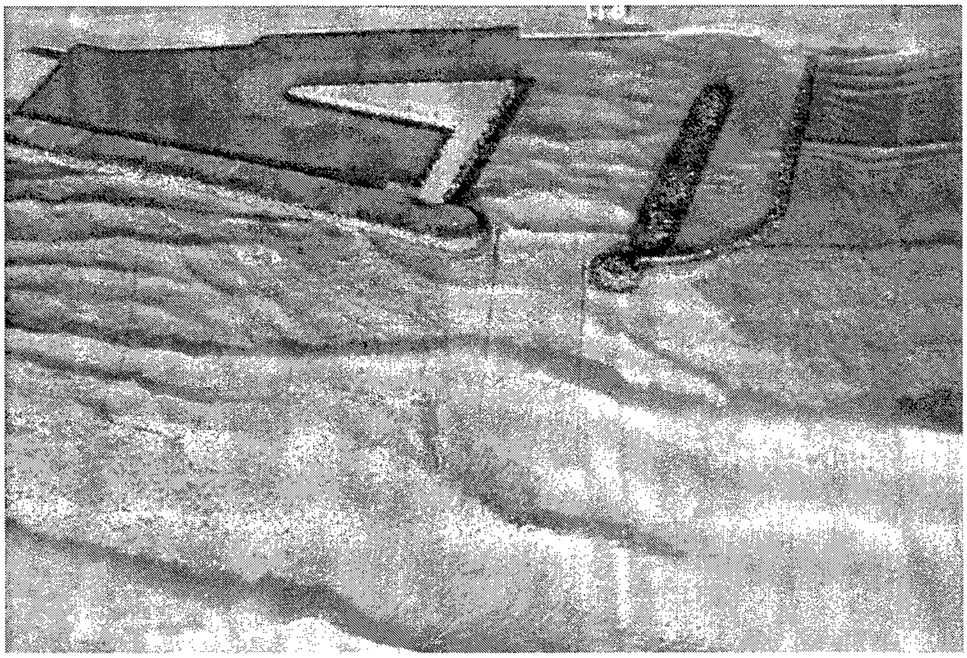


Photo 61. Typical wave patterns for Alternative 8; 18-sec, 8-ft waves from 180 deg; swl = +1.0 ft mllw

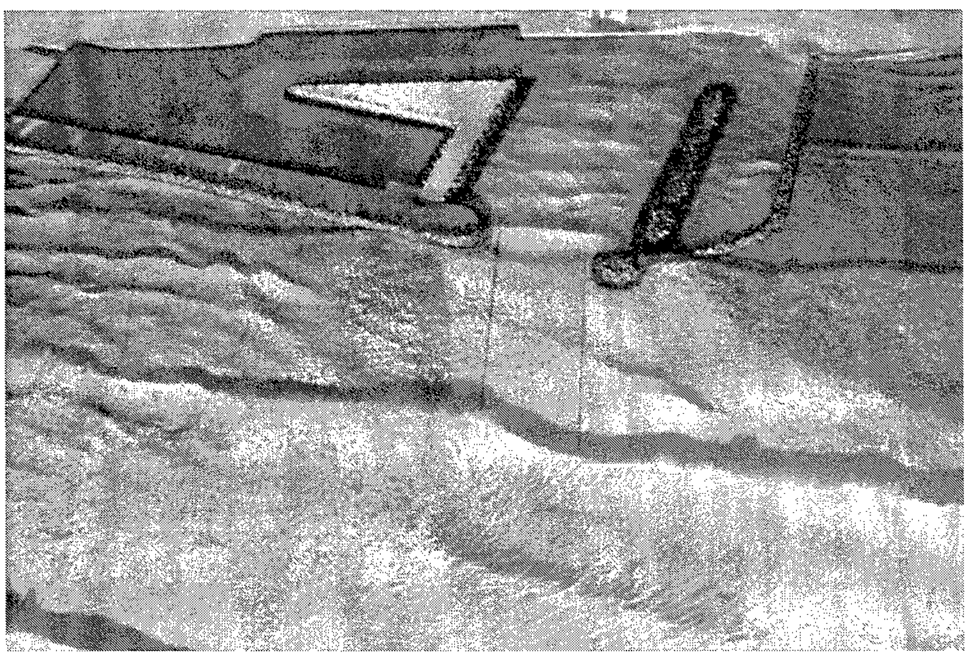


Photo 62. Typical wave patterns for Alternative 8; 18-sec, 8-ft waves from 180 deg; swl = +2.3 ft mllw

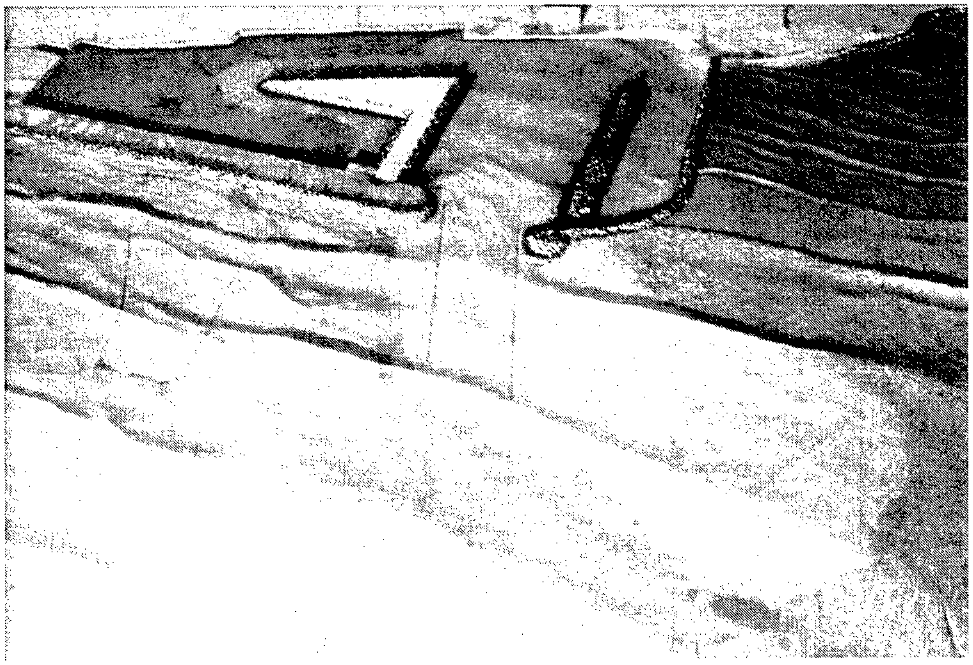


Photo 63. Typical wave patterns for Alternative 8; 8-sec, 3-ft waves from 215 deg; swl = +1.0 ft mllw

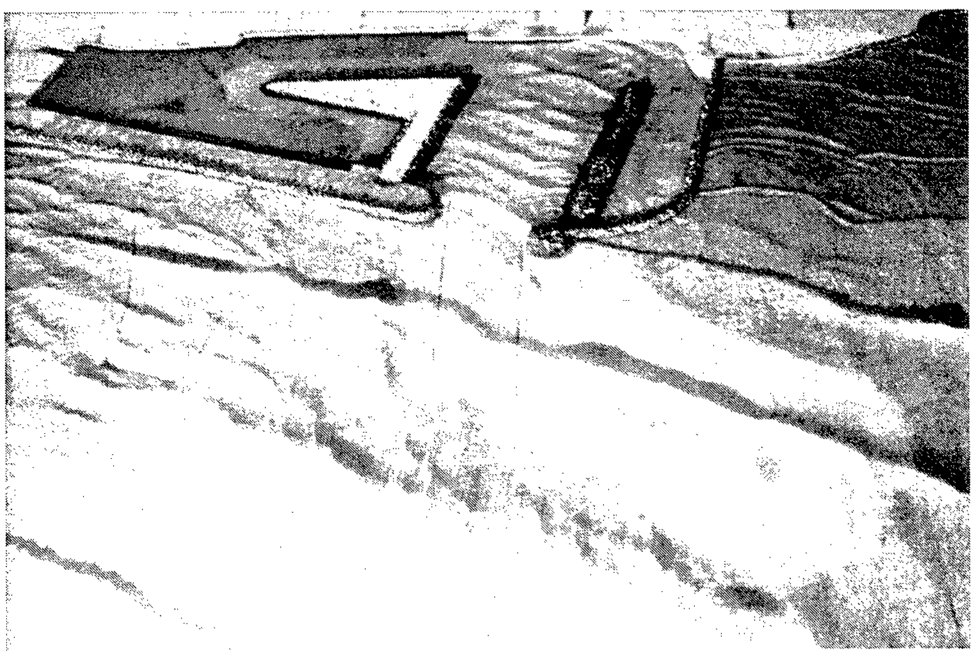


Photo 64. Typical wave patterns for Alternative 8; 14-sec, 6-ft waves from 215 deg; swl = +1.0 ft mllw

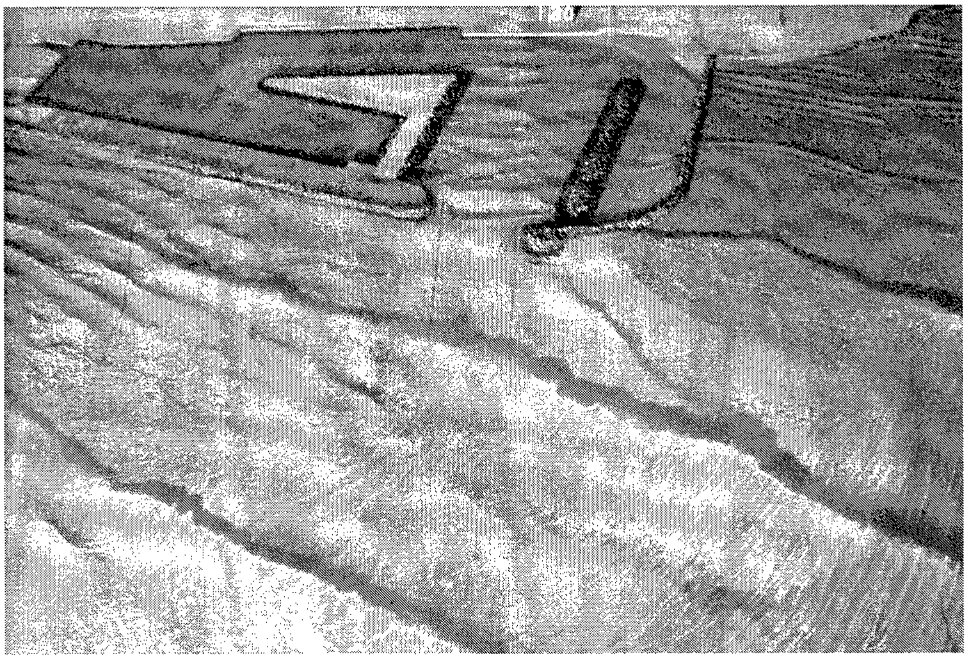


Photo 65. Typical wave patterns for Alternative 8; 18-sec, 8-ft waves from 215 deg; swl = +1.0 ft mllw

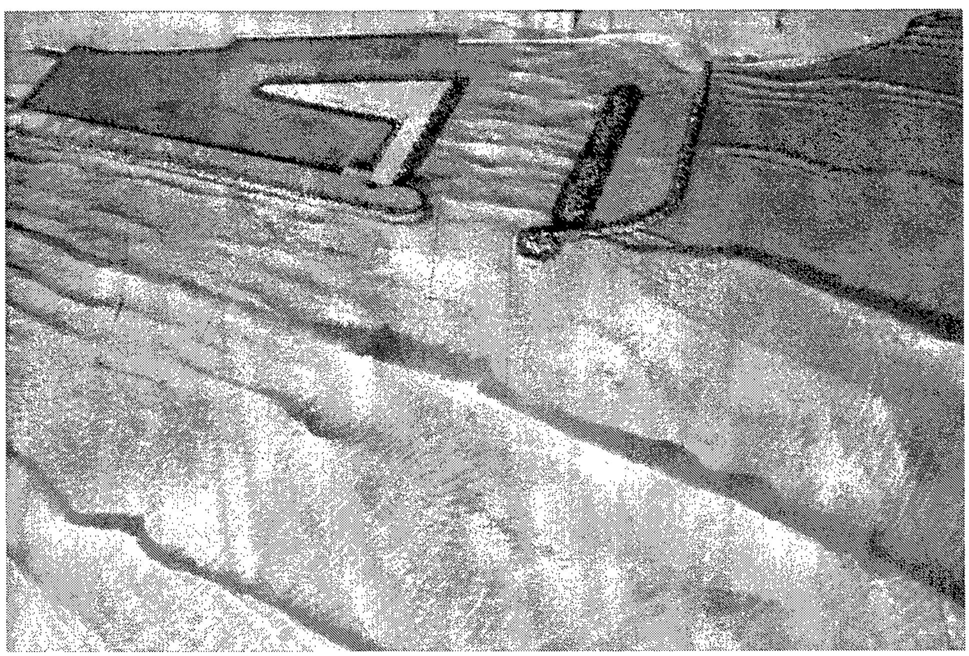
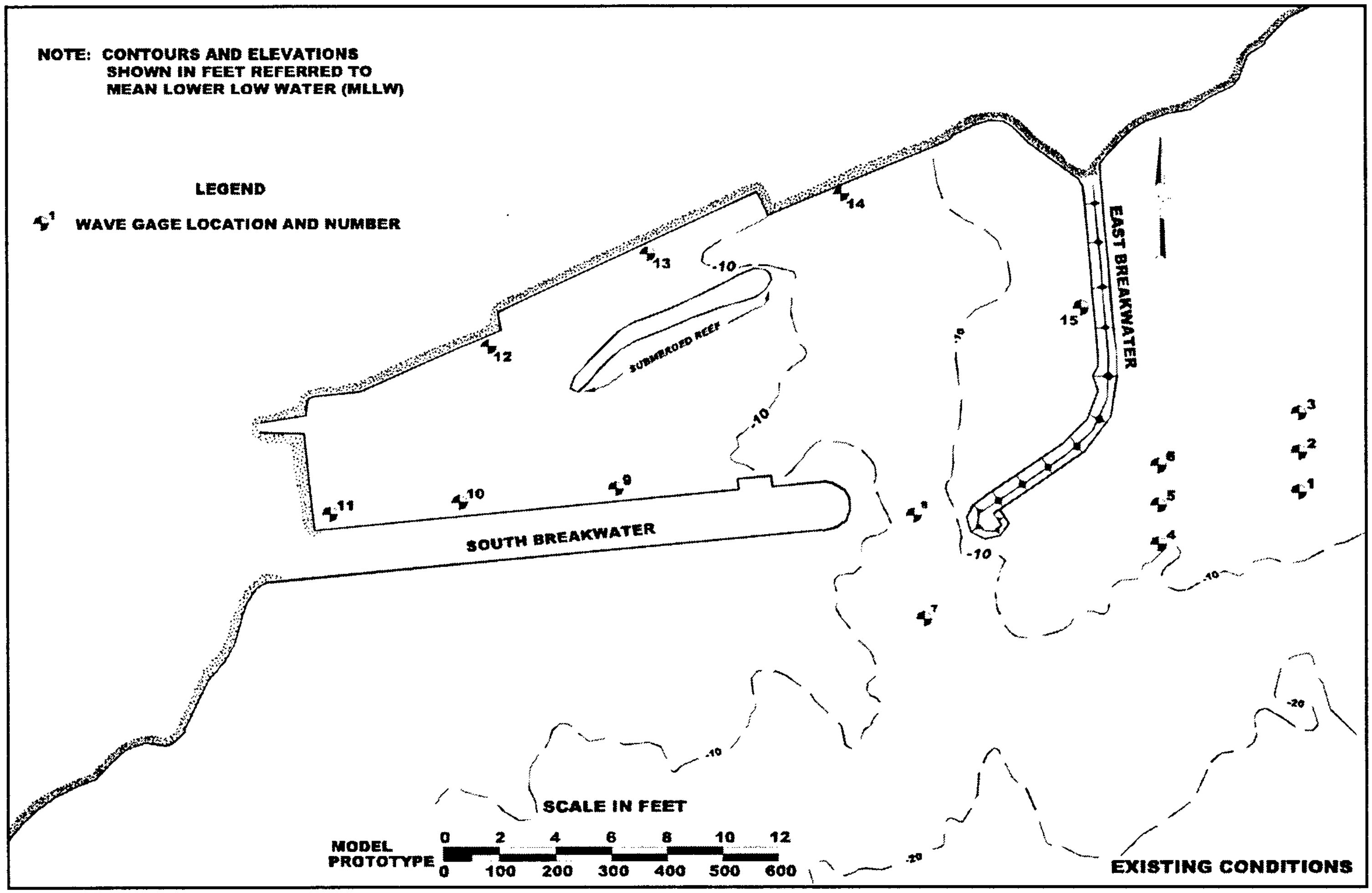
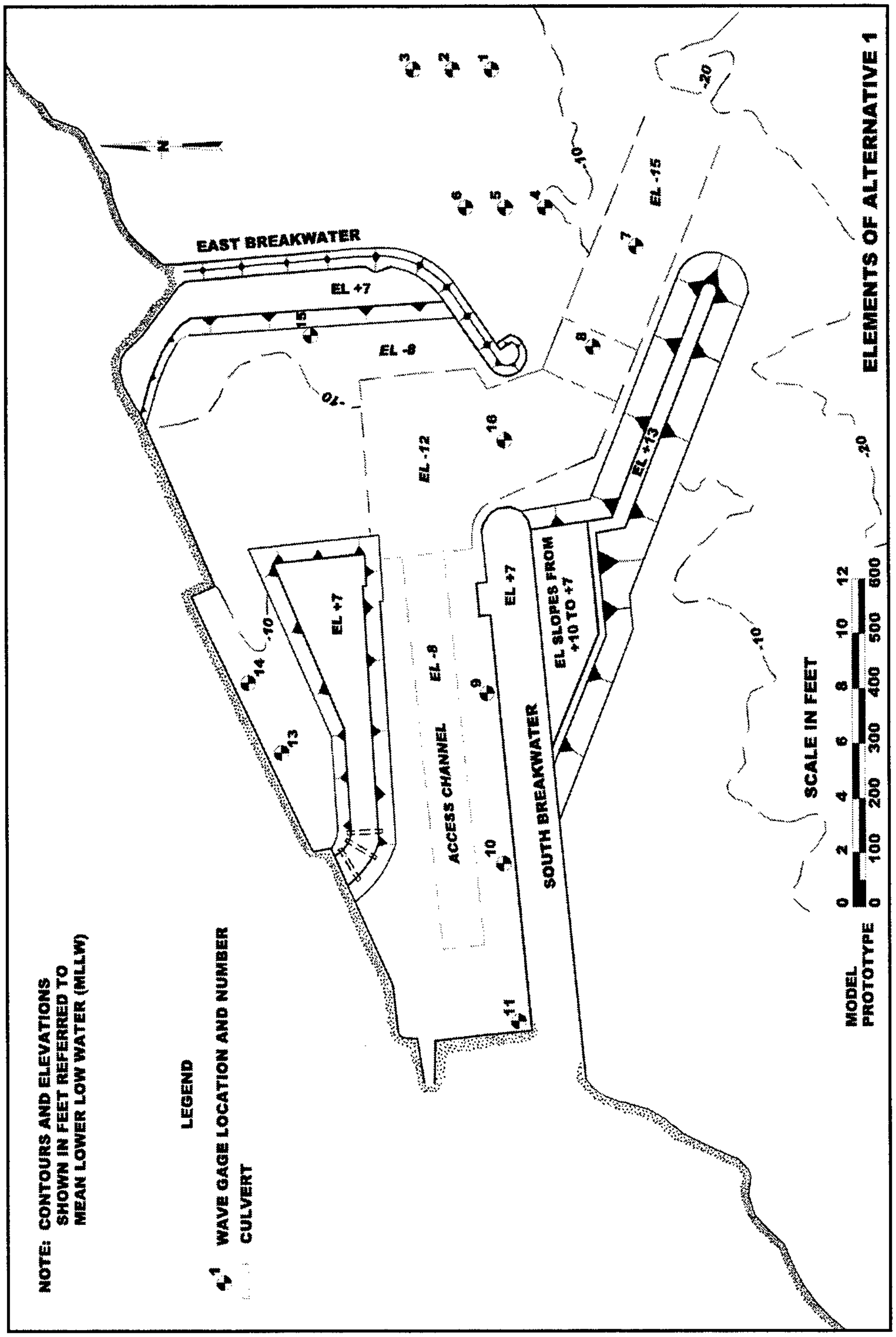


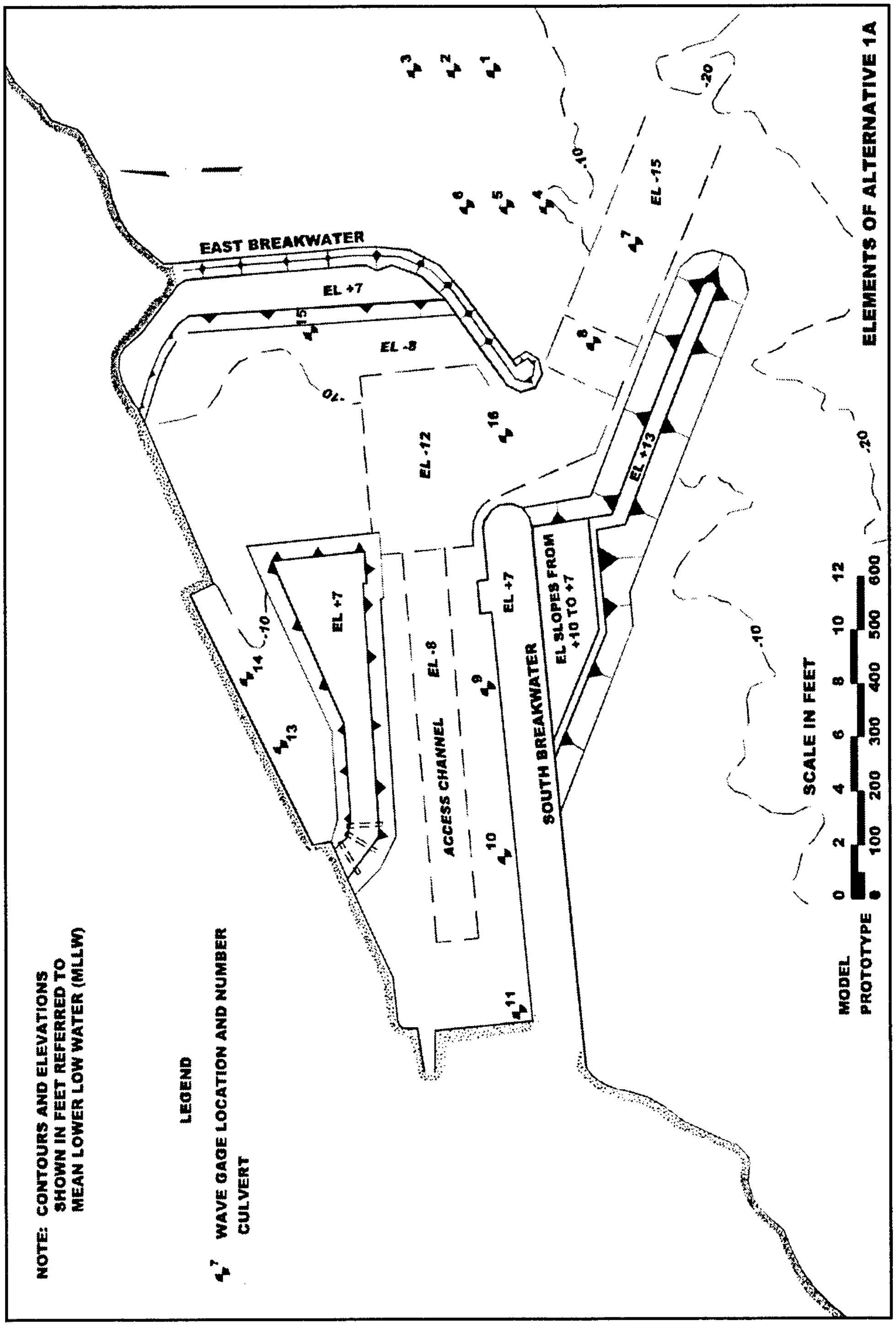
Photo 66. Typical wave patterns for Alternative 8; 18-sec, 8-ft waves from 215 deg; swl = +2.3 ft mllw


NOTE: CONTOURS AND ELEVATIONS
SHOWN IN FEET REFERRED TO
MEAN LOWER LOW WATER (MLLW)
LEGEND
1 WAVE GAGE LOCATION AND NUMBER
EAST BREAKWATER
SOUTH BREAKWATER
SUBMERGED REEF
-10
-20
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
SCALE IN FEET
MODEL 0 2 4 6 8 10 12
PROTOTYPE 0 100 200 300 400 500 600
EXISTING CONDITIONS



NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
WAVE GAGE LOCATION AND NUMBER
CULVERT
N
EAST BREAKWATER
EL +7
EL -8
EL -12
EL -15
EL +13
EL -8
EL +7
EL +7
ACCESS CHANNEL
SOUTH BREAKWATER
EL SLOPES FROM +10 TO +7
-10
-20
1
2
3
4
5
6
7
8
9
10
11
13
14
15
16
SCALE IN FEET
MODEL 0 2 4 6 8 10 12
PROTOTYPE 0 100 200 300 400 500 600
ELEMENTS OF ALTERNATIVE 1

Plate 2



NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
WAVE GAGE LOCATION AND NUMBER
CULVERT
EAST BREAKWATER
EL +7
EL -8
EL -12
EL -15
EL +13
EL +7
EL +7
EL -8
ACCESS CHANNEL
SOUTH BREAKWATER
EL SLOPES FROM +10 TO +7
SCALE IN FEET
MODEL 0 2 4 6 8 10 12
PROTOTYPE 0 100 200 300 400 500 600
ELEMENTS OF ALTERNATIVE 1A

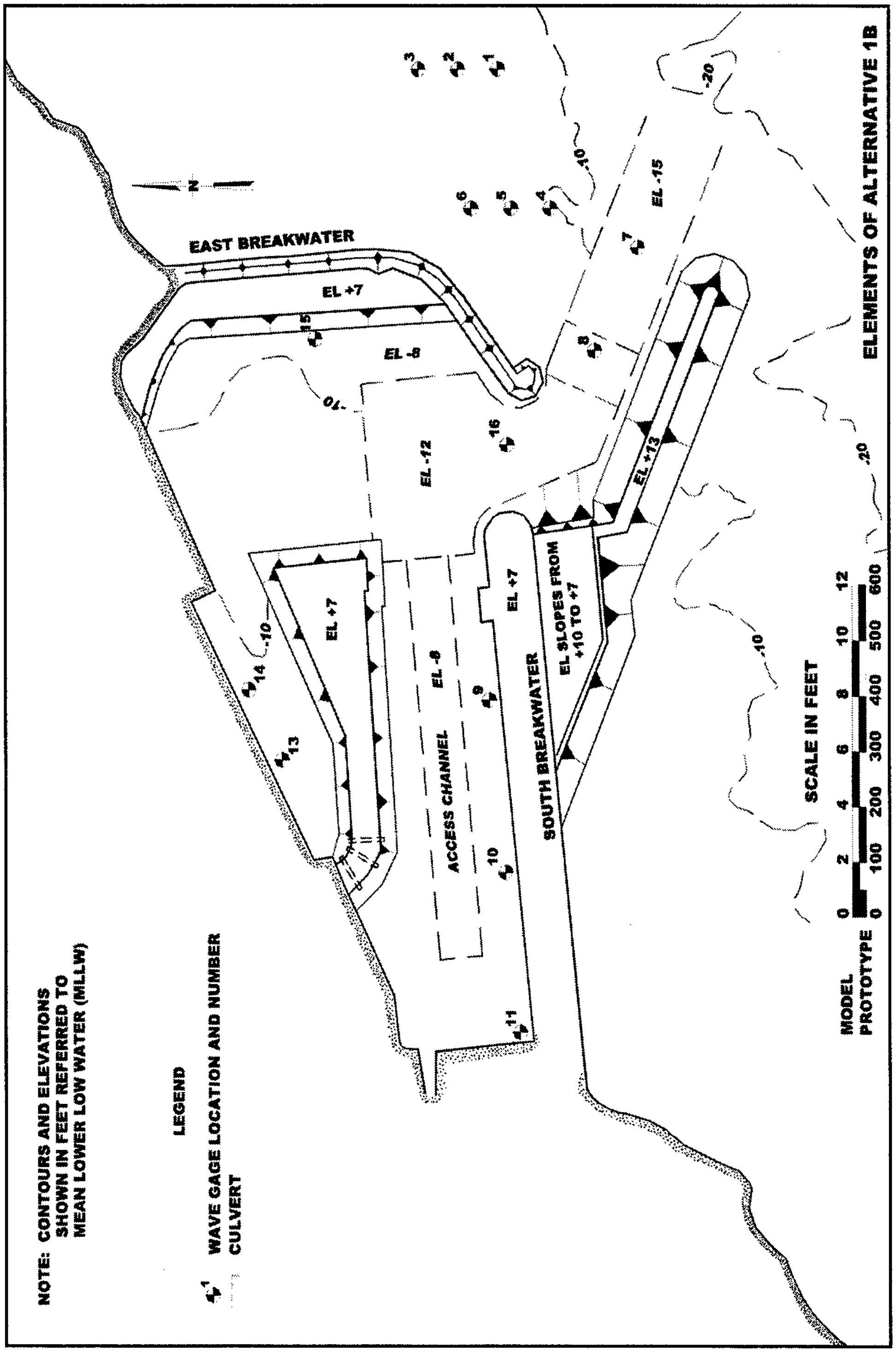
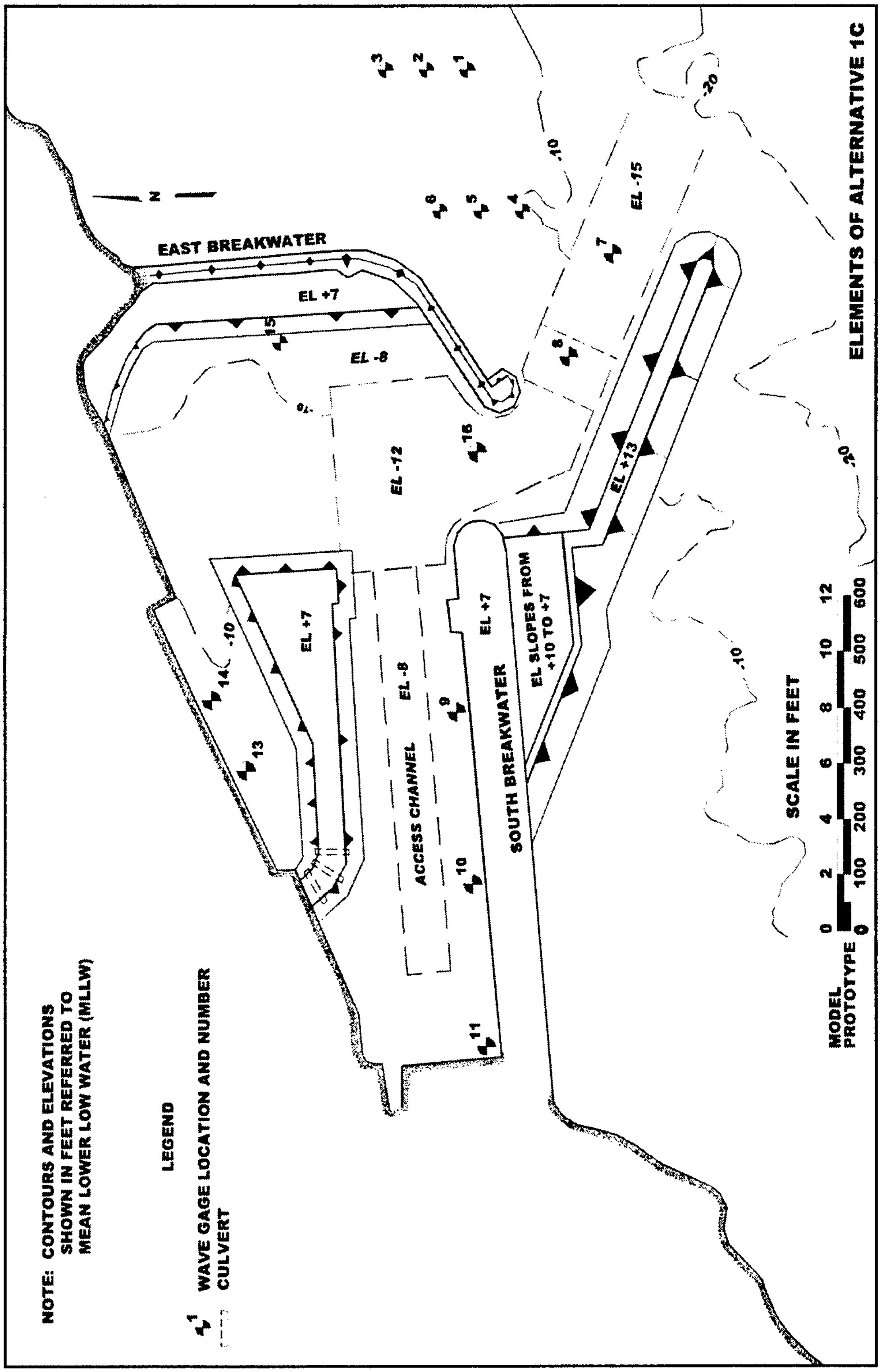

ELEMENTS OF ALTERNATIVE 1B
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
WAVE GAGE LOCATION AND NUMBER
CULVERT
EAST BREAKWATER
SOUTH BREAKWATER
ACCESS CHANNEL
EL +7
EL -8
EL -12
EL -15
EL +13
EL SLOPES FROM +10 TO +7
-10
-20
N
SCALE IN FEET
MODEL 0 2 4 6 8 10 12
PROTOTYPE 0 100 200 300 400 500 600

Plate 4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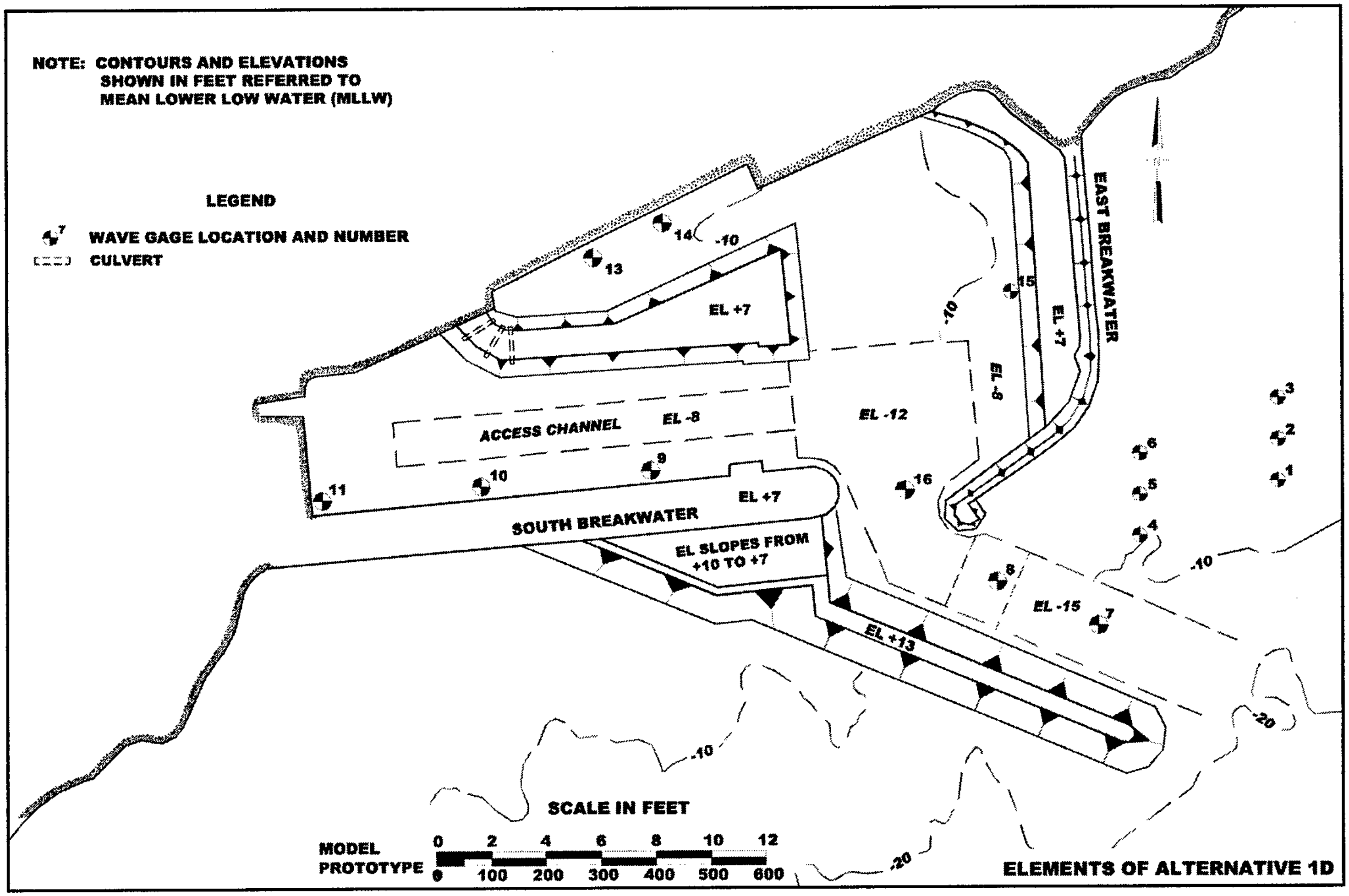
LEGEND
WAVE GAGE LOCATION AND NUMBER
CULVERT
N
EAST BREAKWATER
EL +7
EL -8
EL -12
EL -15
EL +13
ACCESS CHANNEL
SOUTH BREAKWATER
EL SLOPES FROM +10 TO +7
-10
-20
SCALE IN FEET
MODEL 0 2 4 6 8 10 12
PROTOTYPE 0 100 200 300 400 500 600
ELEMENTS OF ALTERNATIVE 1C



NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
WAVE GAGE LOCATION AND NUMBER
CULVERT
EAST BREAKWATER
SOUTH BREAKWATER
ACCESS CHANNEL
EL +7
EL -8
EL -12
EL -15
EL +13
EL SLOPES FROM +10 TO +7
-10
-20
1
2
3
4
5
6
7
8
9
10
11
13
14
15
16
SCALE IN FEET
MODEL 0 2 4 6 8 10 12
PROTOTYPE 0 100 200 300 400 500 600
ELEMENTS OF ALTERNATIVE 1D

Plate 6

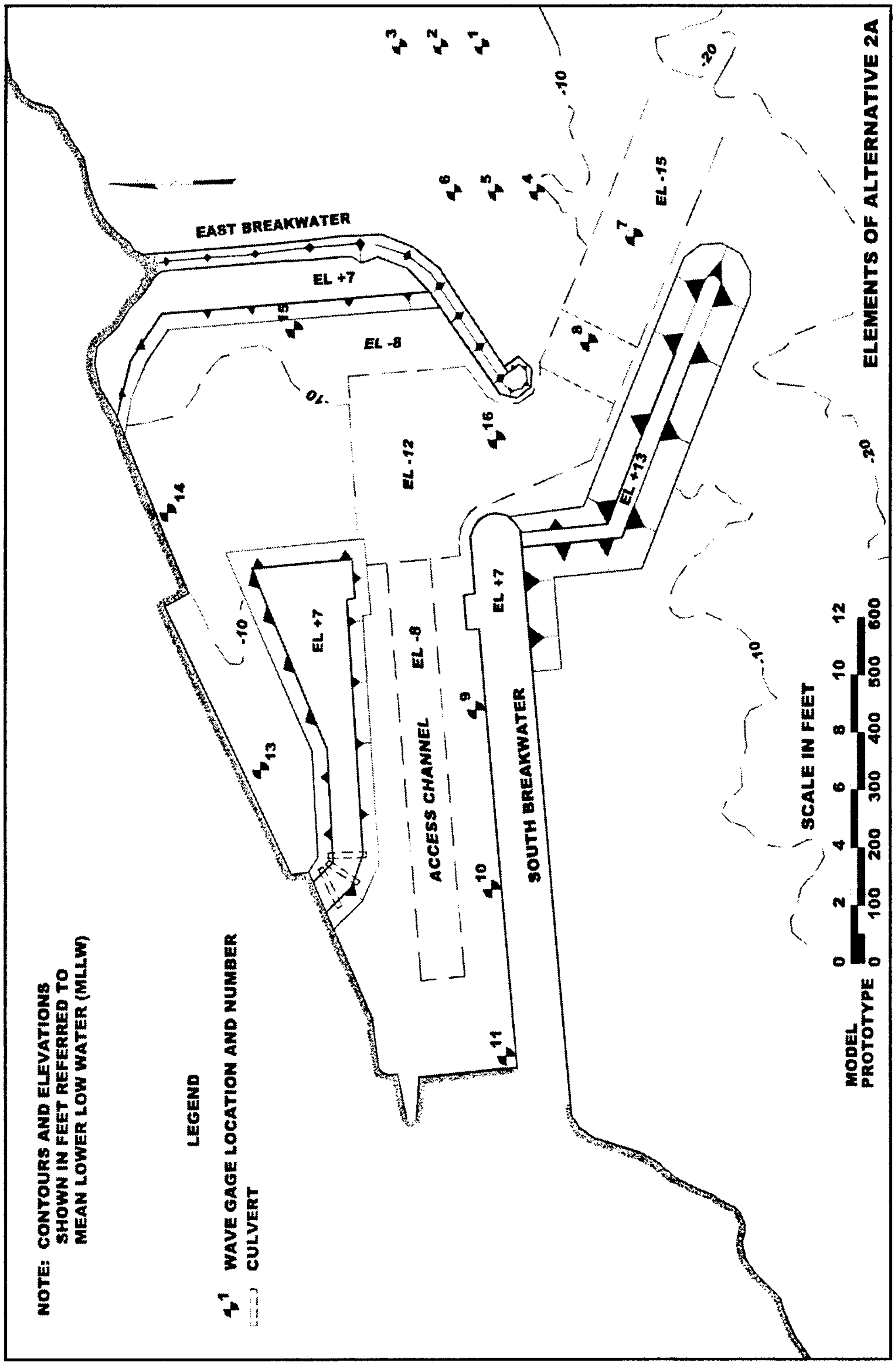

ELEMENTS OF ALTERNATIVE 2A
EAST BREAKWATER
SOUTH BREAKWATER
ACCESS CHANNEL
EL +7
EL -8
EL -12
EL -15
EL +13
-10
-20
SCALE IN FEET
MODEL 0 2 4 6 8 10 12
PROTOTYPE 0 100 200 300 400 500 600
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
WAVE GAGE LOCATION AND NUMBER
CULVERT

Plate 7

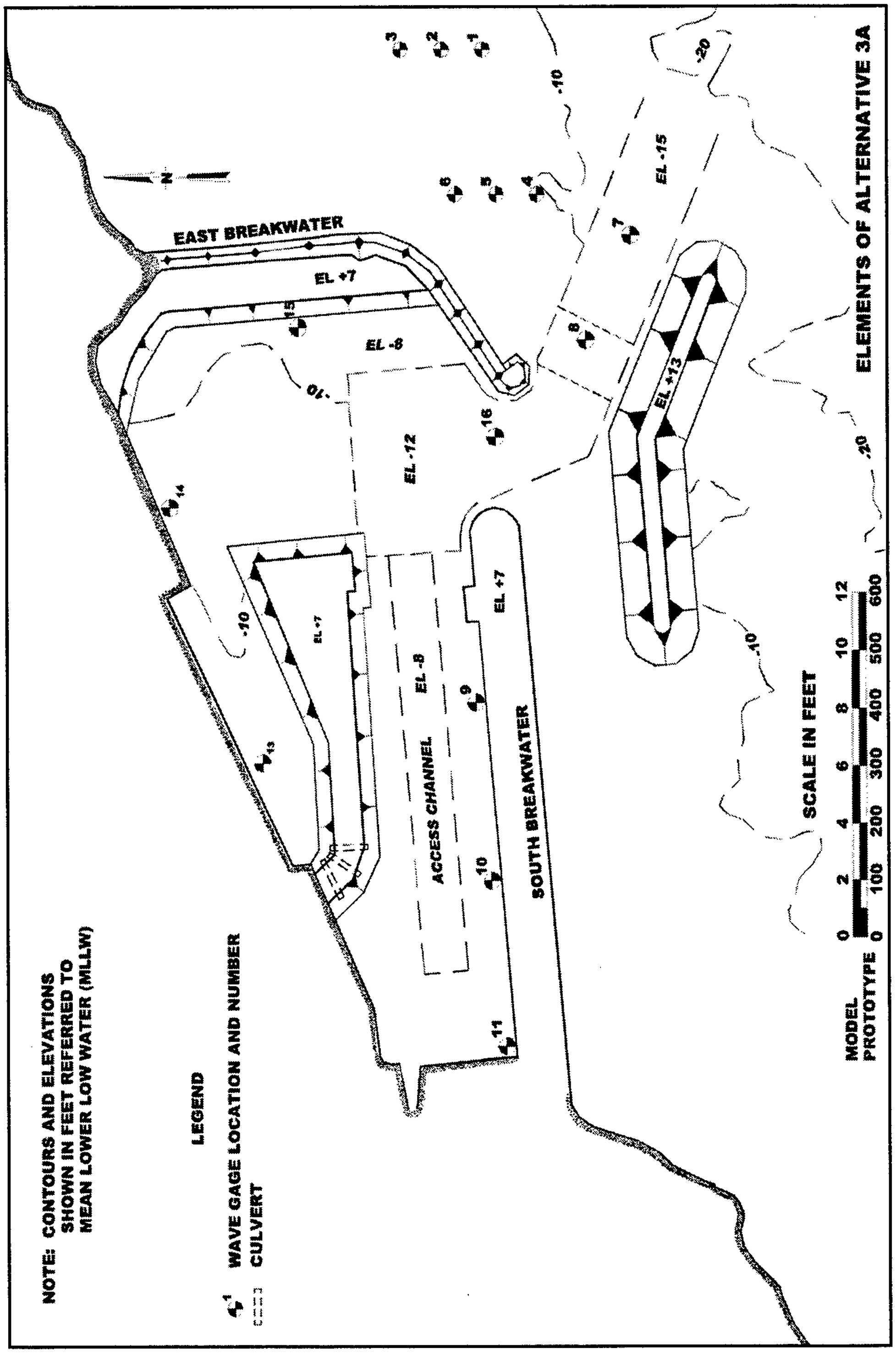

NOTE: CONTOURS AND ELEVATIONS
SHOWN IN FEET REFERRED TO
MEAN LOWER LOW WATER (MLLW)
LEGEND
WAVE GAGE LOCATION AND NUMBER
CULVERT
EAST BREAKWATER
EL +7
EL -8
-10
EL -12
EL +7
ACCESS CHANNEL
EL -8
SOUTH BREAKWATER
EL +7
EL +13
EL -15
-10
-20
SCALE IN FEET
MODEL 0 2 4 6 8 10 12
PROTOTYPE 0 100 200 300 400 500 600
N
ELEMENTS OF ALTERNATIVE 3A

Plate 8

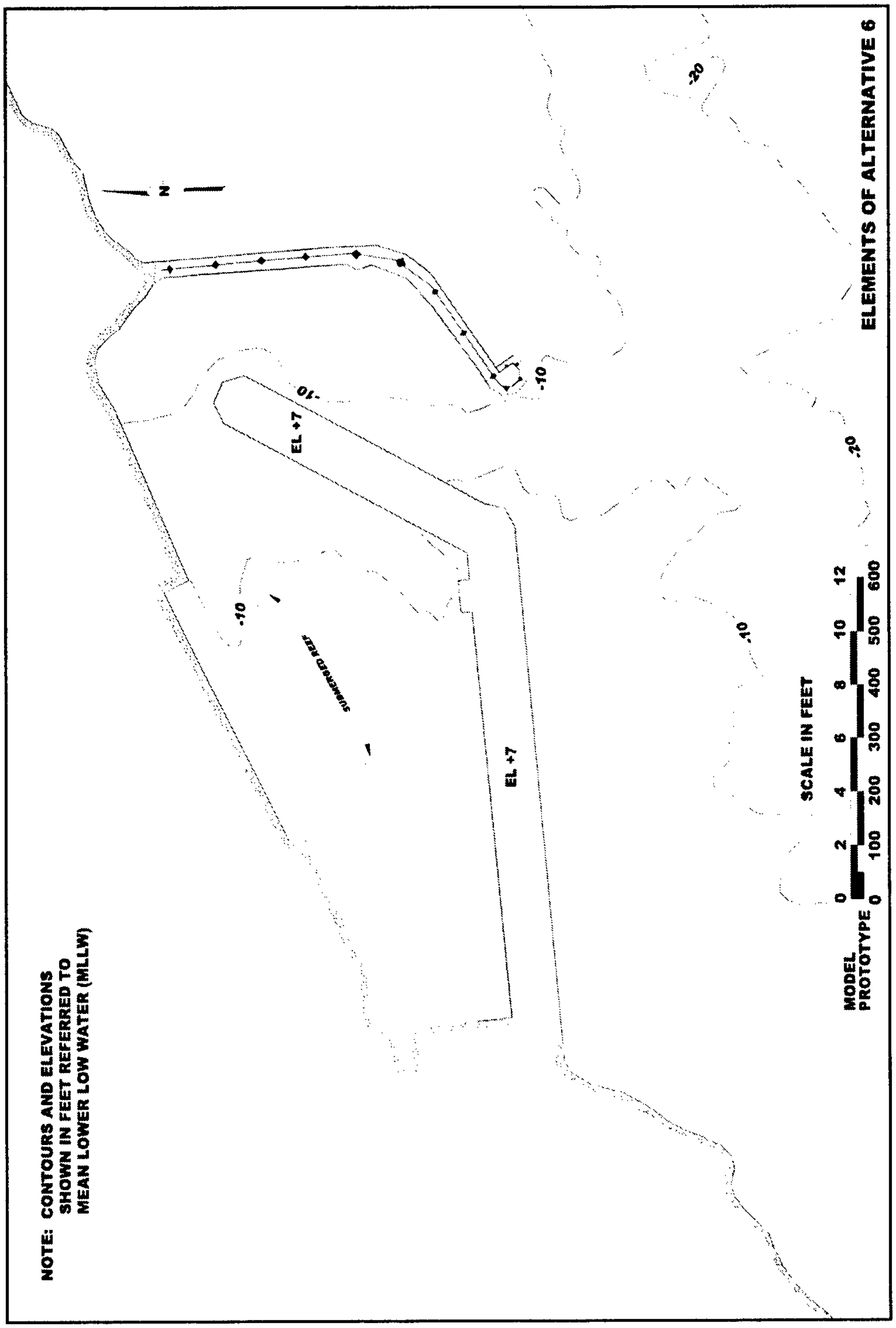
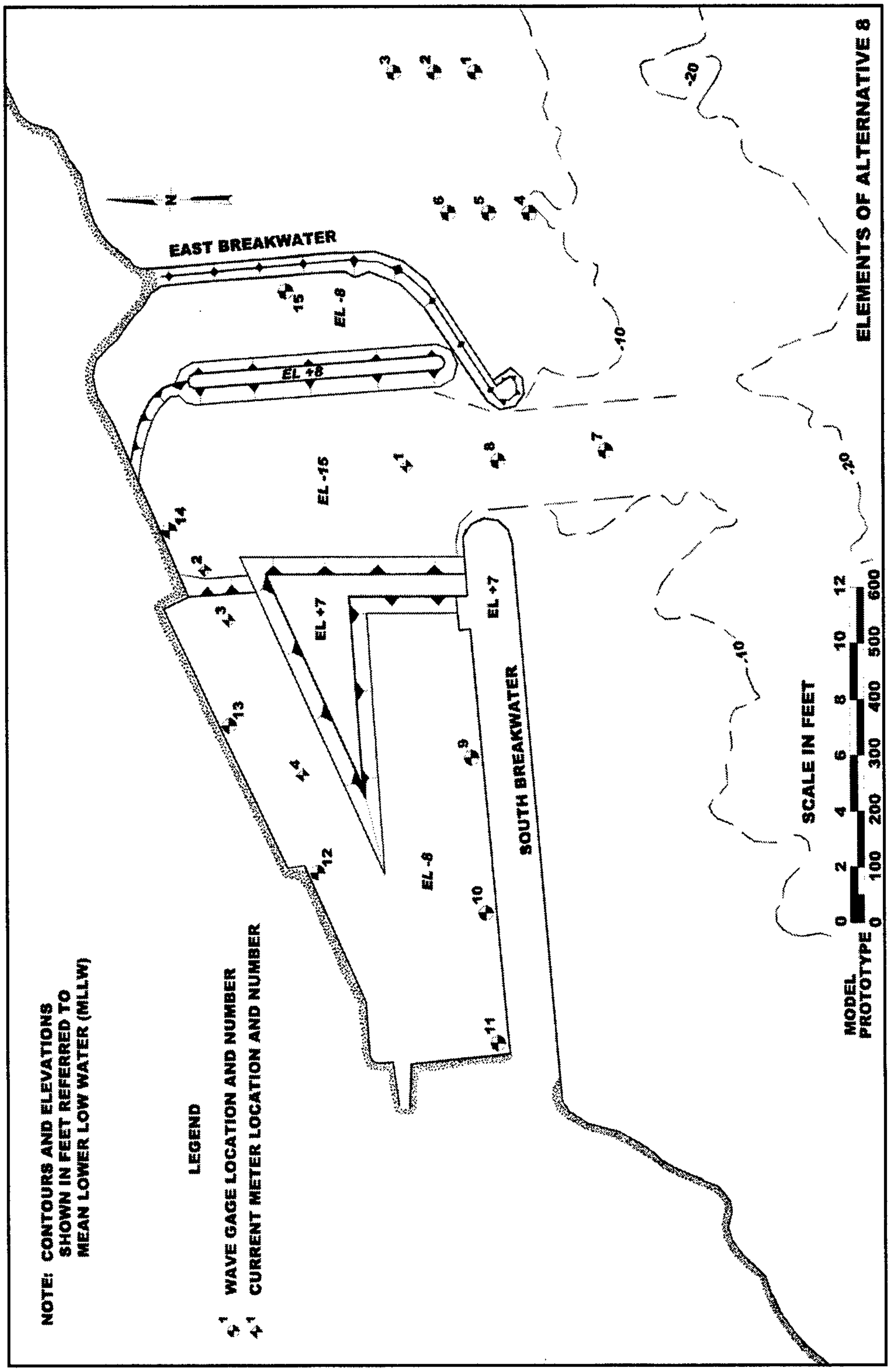

NOTE: CONTOURS AND ELEVATIONS
SHOWN IN FEET REFERRED TO
MEAN LOWER LOW WATER (MLLW)
N
EL +7
EL +7
-10
-10
-10
-10
-20
-20
SUBMERGED REEF
SCALE IN FEET
MODEL 0 2 4 6 8 10 12
PROTOTYPE 0 100 200 300 400 500 600
ELEMENTS OF ALTERNATIVE 6

Plate 9



ELEMENTS OF ALTERNATIVE 8
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
WAVE GAGE LOCATION AND NUMBER
CURRENT METER LOCATION AND NUMBER
EAST BREAKWATER
SOUTH BREAKWATER
EL -8
EL +8
EL -15
EL +7
EL +7
EL -8
-10
-20
-20
-10
N
SCALE IN FEET
MODEL 0 2 4 6 8 10 12
PROTOTYPE 0 100 200 300 400 500 600

Plate 10

Appendix A
Comparison of Numerical and Physical Models

Background

In years prior to the physical model studies described in this report, various Maalaea Harbor layout alternatives were investigated with numerical model studies (Hadley, Thompson, and Wilson 1998; Thompson and Hadley 1994; Lillycrop et al. 1993).[1] Several alternatives considered with numerical modeling are similar to physical model test plans. Although physical model studies were not intended to match any particular numerical model studies, there are enough similarities in the studies to merit a brief comparison between numerical and physical model results.

The most recent numerical model studies (Hadley, Thompson, and Wilson 1998) are compared with physical model studies in this appendix. Comparisons were made between selected gages in the existing harbor, Alternative 1, and Alternative 8. Important differences between studies, which affect the comparisons, are as follows:

a. The numerical model seaward boundary extended to a maximum depth of about 7.6 m (25 ft), while the physical model seaward boundary extended to a 12.8-m (42-ft) depth mllw. Thus, the physical model included a more comprehensive representation of the shallow seafloor outside the entrance to Maalaea Harbor.

b. The numerical model represented incident waves as a directionally-spread spectrum, while the physical model relied on a unidirectional, wave approach.

c. Numerical model studies used a mean lower low water (mllw) water level. Physical model studies used water levels of +0.3 m (1.0 ft) mllw (equal to mean tide level) and +0.7 m (2.3 ft) mllw. The tidal range is 0.5 m (1.6 ft).

[1] All references cited in this appendix are listed in the References section at the end of the main text.

d. The Harbor Wave Oscillation Model (HARBD) numerical model does not include wave breaking or other effects related to wave height (linear model). The physical model naturally includes wave height-related effects, such as breaking and breakwater overtopping.

e. The HARBor Deepwater (HARBD) numerical model includes energy only at wind wave and swell periods introduced in the incident wave conditions. The physical model naturally develops long-period energy near and inside the harbor due to nonlinear hydrodynamic processes. The physical model also allows natural decomposition of swell waves into shorter waves over the reef, as shown in photos accompanying this report. Finally, the physical model allows currents to naturally form in response to wave breaking on the reefs.

f. The numerical model represents breakwaters as solid barriers. The physical model allows wave transmission through porous structures, such as the existing east breakwater and the Alternative 1 extension of the south breakwater.

g. Representation of existing harbor layout: the shoal area centrally located inside the harbor basin had a different configuration in numerical and physical models. Areas landward of the shoal are most affected in the comparisons (physical model Gages 12-14).

h. Representation of Alternative 1 layout: entrance channel width was up to 55 m (180 ft) in the numerical model versus 46 m (150 ft) in the physical model.

i. Representation of Alternative 8 layout: Alternative 8 in the physical model somewhat resembles Plan 6 in numerical model studies, in that both layouts have the same entrance channel alignment and no structural additions outside the confines of the existing harbor. Entrance channel depth is 5 m (15 ft) in both, but width is 46-61 m (150-200 ft) in the numerical model versus 46 m (150 ft) in the physical model. Layout of interior structures is quite different between the numerical and physical models.

Existing Harbor Comparisons

In the existing harbor, physical model Gages 9-10 and 12-15 were paired with nearby output stations in numerical model studies. Initially, physical model Gage 11 was also considered, but its location in the southwest corner of the harbor is strongly affected by long-period harbor oscillations and comparisons with the numerical model were not meaningful, as previously discussed in item *e*. Only physical model tests with +0.3 m (1.0-ft) mllw water level were considered.

The numerical model studies provide results at selected harbor locations in the form of amplification factors, defined as local wave height divided by incident wave height. These results depend on incident wave period and direction, but not height (see item *d*).

For comparison, physical model results given in this report were converted to amplification factors. This required that physical model wave heights at the selected gages be divided by incident wave height. Incident wave height should represent the approximate location of the numerical model boundary, not the actual physical model incident height. Thus, physical model incident wave conditions were transformed to 7.6-m (25-ft) depth, using a directional spectral wave model and straight, parallel bottom contours. Each physical model gage wave height was then divided by the computed incident wave height at 7.6-m (25-ft) depth.

To best match numerical and physical model incident wave direction cases, wave direction at the numerical model boundary had to be considered. For the numerical model, that direction included transformation of the deepwater incident wave with model Shallow Wave (SHALWV) up to the HARBD seaward boundary, as discussed by Lillycrop et al. (1993). For the physical model, that direction was for the incident wave transformed to 7.6-m (25-ft) depth, as previously discussed.

Peak wave periods considered in numerical model studies span the range tested in the physical model, but do not exactly coincide with the particular values used.

Finally, numerical and physical model cases were paired to best match incident wave periods and directions at the numerical model seaward boundary. Numerical and physical model periods were within 1 sec of each other, and directions were within 5 deg, in most cases. Physical model results for 14-, 16-, and 18-sec period include multiple wave heights. For these cases, amplification factors were averaged to give a single value for each period and direction combination.

Paired amplification factors are shown in Figure A1. Points are identified by physical model gage and incident direction. The same symbols are used for both the 160-deg and 180-deg cases. Most of these points represent the 180-deg case. Only one 160-deg case (8-sec period) could be matched with the numerical model, and it was similar to the 180-deg case.

Because of the differences between numerical and physical model studies (items *a* through *g*), the comparisons cannot be considered too definitively. However, several general observations can be made.

The difference in bathymetric coverage (item *a*) appears to be a significant factor. Physical model photos show evidence of waves from 160-deg and 180-deg decreasing in height over the natural channel seaward of the harbor entrance, giving a reduced wave height entering the harbor. Photos show waves from 215 deg can be intensified over the reef structure west of the entrance channel, giving an increased wave height entering the harbor. These processes begin outside the area covered by numerical model bathymetry and, hence, are not fully included in numerical model results. These processes contribute to the tendency for the numerical model to overestimate 160-deg and 180-deg cases and underestimate 215-deg cases at Gage 15. The inclusion of directional spreading in numerical model studies may also contribute to a tendency to be higher than the physical model for 160-deg and 180-deg cases. Physical model cases with the highest amplification factors, above 0.7, are 14-sec and 16-sec period cases.

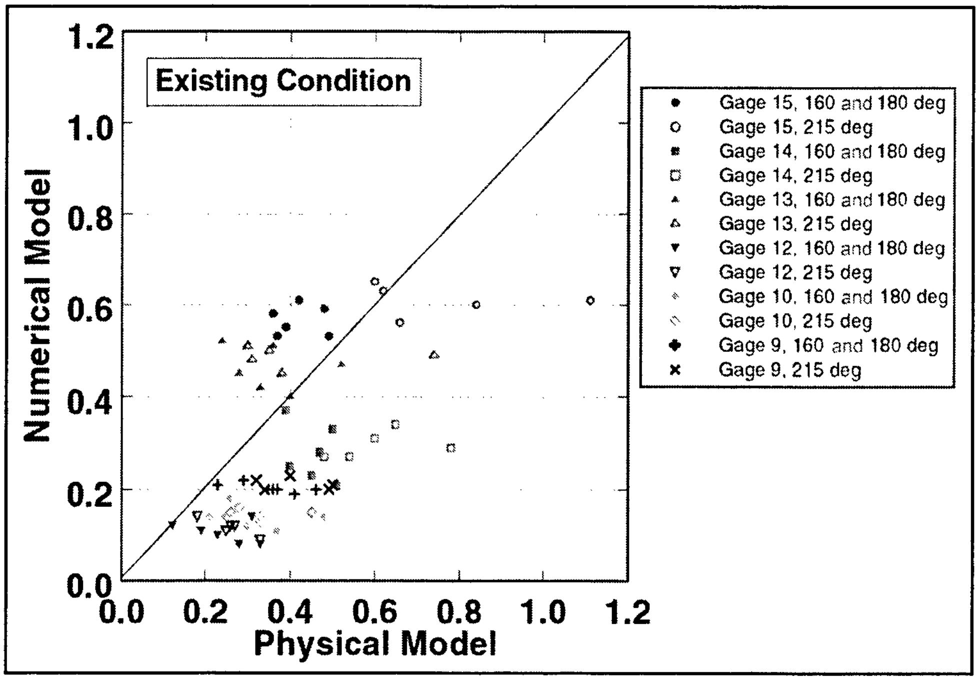


Figure A1. Wave height amplification factor comparison, existing harbor

Comparisons at Gages 12-14 are difficult to interpret because they are strongly impacted by the planform and elevation of the centrally located shoal area (item *g*). Most of the sheltered gages show a clear tendency for physical model amplification factors to be higher than those from the numerical model. These protected locations may be affected more by long-period oscillations in the harbor than by wind wave and swell energy propagating through the entrance. The physical model includes naturally-developing long-period waves, but the numerical model does not (item *e*).

Alternative 1 Comparisons

Numerical and physical model comparisons were made for Alternative 1, as with the existing harbor. Again, Gage 11 was omitted because of the strong impact of harbor oscillations in the physical model.

Paired amplification factors are shown in Figure A2. Amplification factors are generally lower than for the existing harbor, reaching a maximum of about 0.3 for the numerical model and 0.6 for the physical model. Because of the long extension to the south breakwater and the reoriented entrance channel, differences in bathymetric coverage do not appear to impact model results as in the existing harbor. Physical model amplification factors are higher than numerical model amplification factors in nearly every case. The differences are fairly consistent from gage to gage, ranging from about 0.0 to 0.3. The highest physical model amplification factors correspond to periods of 14-18 sec. Notably high amplification factors are evident at Gage 10, which is relatively protected. Long-period harbor oscillations appear to be a major cause of higher amplification factors in the physical model. The deeper entrance channel and porous breakwaters in the physical model may also be allowing more wave energy to penetrate into the harbor (Items *f* and *h*).

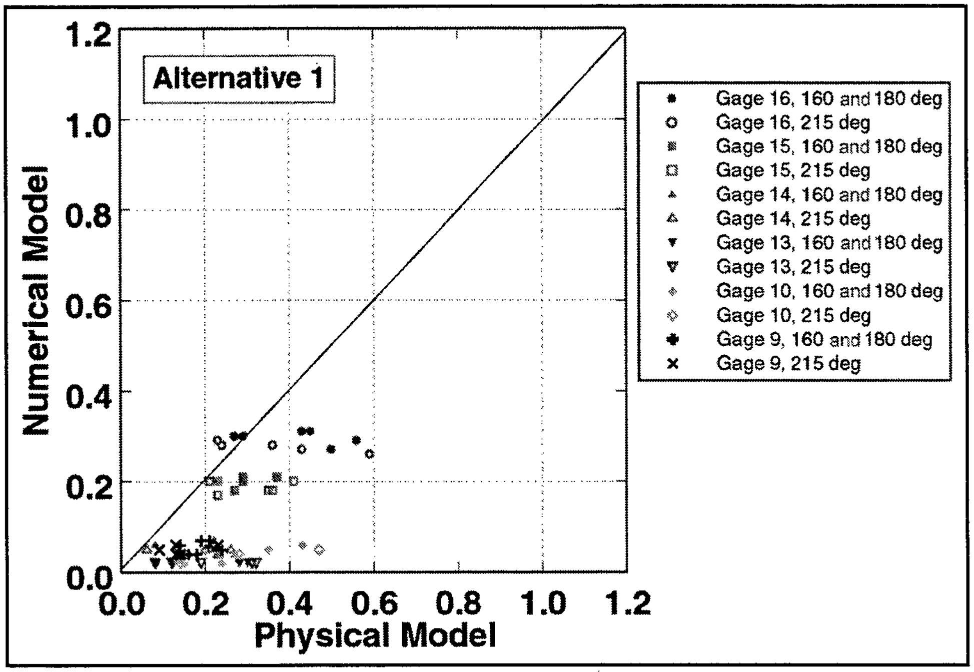


Figure A2. Wave height amplification factor comparison, Alternative 1

Alternative 8 Comparisons

Because of significant differences in layout between physical model Alternative 8 and the best-matching numerical model alternative (item *i*), only Gage 8, in the harbor entrance, was considered for comparison. Paired amplification factors are shown in Figure A3. For both numerical and physical model, these amplification factors are high relative to other cases considered, as would be expected for the relatively exposed location of Gage 8.

Physical model amplification factors exceed numerical model factors in every case. The 215-deg direction cases tend to show higher amplification factors than the 160-deg and 180-deg cases in the physical model. Though not indicated in the figure, physical model amplification factors for a given wave period are greater for the 215-deg direction than for the 160-deg and 180-deg directions in every case. The highest physical model amplification factor, nearly 2.0, corresponds to a 14-sec period. The lowest physical model amplification factors correspond to 8-sec and 11-sec periods.

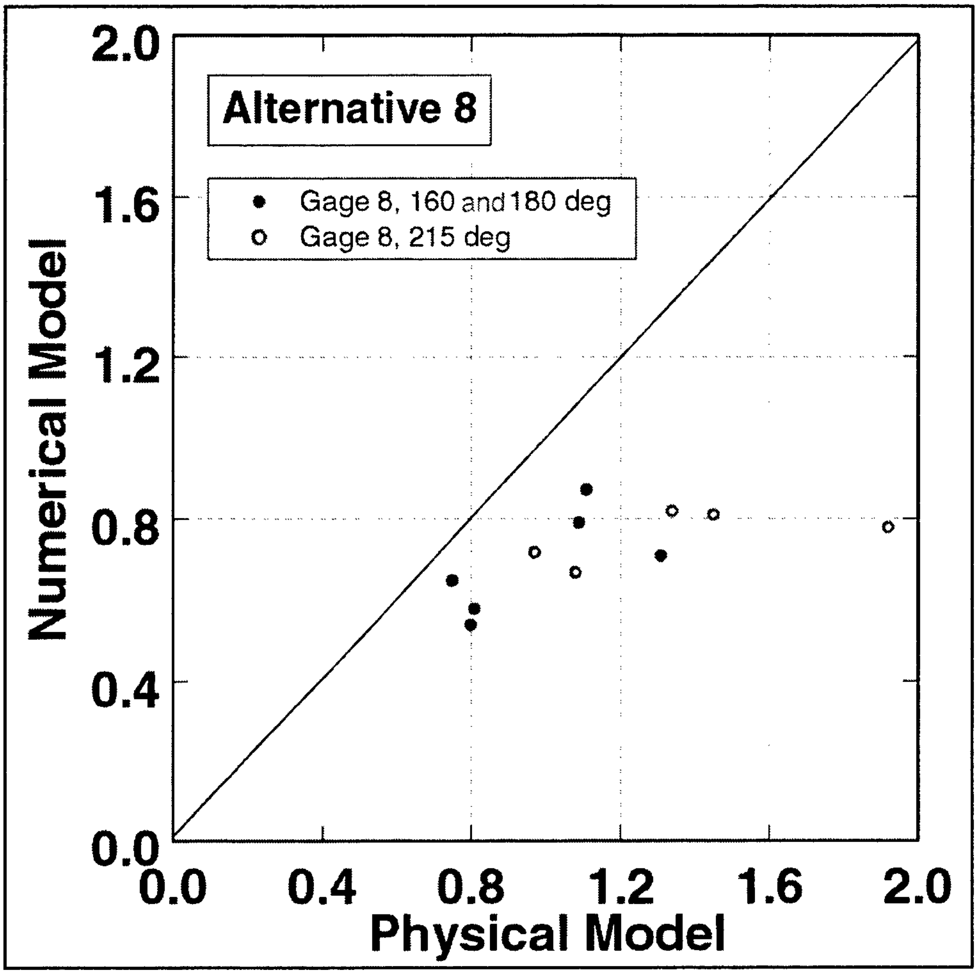


Figure A3. Wave height amplification comparison, Alternative 8

As with the existing harbor, the greater amplification of physical model waves from 215 deg can be attributed to intensification over the reef area just west of the entrance channel, in line with the travel path for waves entering the harbor. Physical model bathymetry represents this shoal area more fully than numerical model bathymetry (item *a*).

The consistent pattern of higher amplification factors in the physical model in every case, as compared to the numerical model, may be explained as follows. Of all the gages and harbor layouts considered in this appendix, this gage is the only one directly exposed to incoming waves. For 160-deg and 180-deg cases, waves propagate nearly straight up the entrance channel to the gage location. The unidirectional waves in physical model tests concentrate all incident wave energy in this single direction. Numerical model tests used a directional spread of wave energy, which would cause more wave energy, approaching oblique to the channel alignment, to refract away from the harbor entrance. For the 215-deg approach direction, Gage 8 still has a direct exposure to incoming waves. However, these waves are coming from a focusing shoal area rather than up the entrance channel. The numerical model, with directionally spread wave energy and a truncated representation of the shoal area, would be expected to give lower amplification factors than the physical model for these cases.

Conclusions

Differences between Maalaea Harbor numerical model and physical model studies make definitive comparisons difficult. However, a few general conclusions can be reached. First, the limited area of bathymetry seaward of the harbor entrance included in the numerical model representation was detrimental to modeling accuracy. The coverage area was dictated by model grid size limitations at the time studies were conducted. Present numerical model technology would no longer have this limitation. Second, inclusion of directional spreading of wave energy in physical model harbor studies may give more realistic results for wind wave and swell energy inside the harbor. Thirdly, physical model studies can naturally include with reasonable accuracy complex but potentially important hydrodynamic phenomena such as wave breaking, decomposition of swell in shallow water into multiple shorter waves, wave-generated currents over reefs, overtopping of breakwaters, transmission through porous structures, and evolution of long-period harbor oscillations. The HARBD numerical model used in previous Maalaea Harbor studies did not include these phenomena. Present numerical model technology is able to address at least some of these phenomena.

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14. ABSTRACT
At the request of the U.S. Army Engineer District, Honolulu, a coastal physical model investigation of Maalaea Harbor was conducted. Purposes of this investigation included (a) evaluating various structural alternatives for reducing wave heights within the harbor, (b) improving navigation conditions at the harbor entrance, and (c) evaluating the effects of the various alternatives on the surfing sites which is believed to be a first for this type of investigation.

Based on results of the coastal model investigation, comparisons with prototype wave data and videos of prototype waves, and opinions of visitors familiar with local surfing conditions at Maalaea Harbor, it is concluded that: (a) the model replicated both the waves that comprise the Maalaea Pipeline and the unacceptably high wave conditions that presently exist within the harbor, and (b) based on the exhaustive wave data presented herein, observations by model operators with extensive experience and observations of visitors familiar with the Maalaea Pipeline, it was concluded that none of the alternatives investigated herein should have a measurable effect on the Maalaea Pipeline.

15. SUBJECT TERMS

Breakwaters	Hydraulic models	Wave transmission
Harbors, Hawaii	Surfing waves	

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